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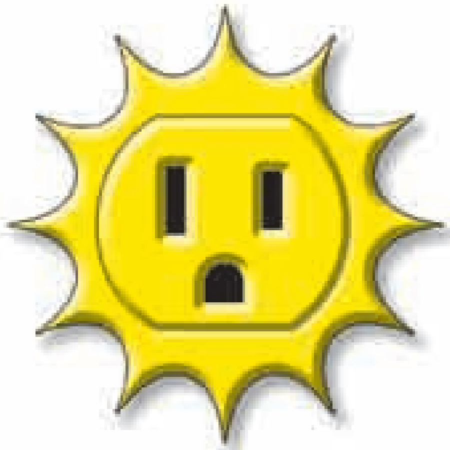

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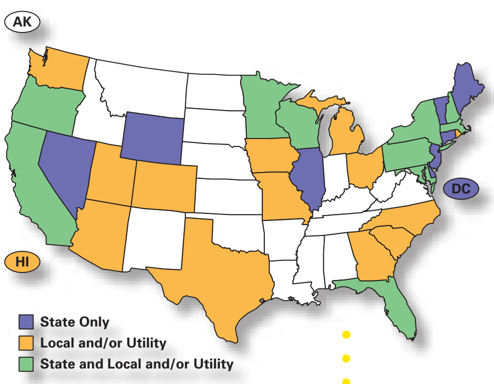
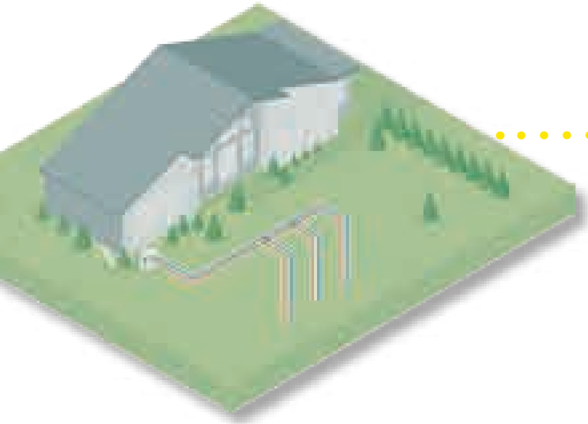
December 2009 & January 2010





Photos (clockwise from bottom left): Courtesy ClimateMaster; www.topherdonahue.com; courtesy www.dsireusa.org; courtesy www.plymouthenergy.org; courtesy www.sma-america.com; Carol Inouye; courtesy www.heliodyne.com

On the Cover

Marcus Hollins and Thayer Hirsh of Lighthouse Solar install a 100 kW PV system at Movement Climbing & Fitness in Boulder, Colorado.

Photo www.topherdonahue.com

Regulars

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from us to you

Tightening Up

While *Home Power* focuses on both renewable energy technologies and energy efficiency, we have to admit that it's easy to get fixated on the shiny hardware. PV arrays are gorgeous, solar hot water system plumbing can be intoxicating, and spinning wind generators and hydro turbines get us pumped up.

Energy efficiency is the unsung hero on the path of sustainability—the energy strategy that usually offers the lowest cost and the biggest return. But caulk, insulation, and compact fluorescent lightbulbs don't have the glitz of the active techie gear we shell out the big bucks for. But moving toward higher energy efficiency is a move toward *using less energy*, which means our energy-generating systems can be smaller, cheaper, leaner, and meaner—and that is truly exciting.

In most parts of North America, heating and/or cooling are the biggest energy loads in a home. And while the heating component is rarely served by electrical sources (and therefore not directly affected by our choice to use solar-, wind-, or hydro-electricity), it often makes up the largest portion of a home's energy footprint. That's why *thermal* energy efficiency is crucial to lowering your energy costs and your household's environmental footprint.

My family recently began a process of finishing and tightening up the home we began to build in the early 1980s—a leaky, rambling, owner-builder structure. After the initial blower-door test, our insulation and building-envelope consultant announced, "You have a 500-square-inch hole in your house!" All the cracks, holes, broken windows, poorly sealed doors, and uninsulated areas added up to one giant void. It was like having a 20- by 25-inch window left open all the time!

We've since cut that number in half, and are moving further in the process of tightening up our home by insulating, filling holes, weather-stripping doors, and general air sealing, which will dramatically reduce the amount of fuel (wood, in our case) we use to heat with, and will also dramatically increase our comfort.

As another winter approaches, we hope you'll focus on your home's thermal efficiency, and reap the benefits this winter and for years to come.

—Ian Woofenden
for the *Home Power* crew

Think About It...

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—Steven Chu, U.S. Secretary of Energy

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Shifting Energy Sources

Americans used more solar, nuclear, biomass, and wind energy in 2008 than they did in 2007, according to recent energy flow charts released by the Lawrence Livermore National Laboratory (LLNL). The nation used less coal and petroleum during the same time frame and only slightly increased its natural gas consumption. Geothermal energy use remained the same.

The estimated U.S. energy use in 2008 equaled 99.2 quadrillion Btu ("quads"), down from 101.5 quads in 2007. (A Btu or British Thermal Unit is a unit of measurement for energy, and is equivalent to about 1.055 kilojoules.)

Energy use in the industrial and transportation sectors declined by 1.17 and 0.9 quads respectively, while commercial and residential use climbed slightly. The drop in transportation and industrial use—which are both heavily dependent on petroleum—can be attributed to a spike in oil prices in summer 2008.

Last year saw a significant increase in biomass with the recent push for the development of more biofuels.

"This is a good snapshot of what's going on in the country. Some of the year-to-year changes in supply and consumption can be traced to factors such as the economy and energy policy," said A.J. Simon, an LLNL energy systems analyst who develops the energy flow charts using data provided by the Department of Energy's Energy Information Administration.

Simon said the increase in wind energy can be attributed to large investments in wind turbine technologies over the last few years as well as better use of the existing turbines.

Nuclear energy also saw a slight increase from 8.41 quads in 2007 up to 8.45 quads in 2008. While no new nuclear power plants came on-line in 2008, the existing plants had less downtime. Over the last 20 years, the downtime for maintenance and refueling at nuclear power plants had been decreasing.

"There's an incentive to operate as much as possible," Simon said. "It's a smart thing to do. You can't earn revenue by selling electricity when you're down."

The chart also shows the amount of energy rejected by the United States. Of the 99.2 quads consumed, only 42.15 ended up as energy services. Energy services are "things that make our lives better," Simon said. "That's the energy that makes your car move and that comes out of your light bulb."

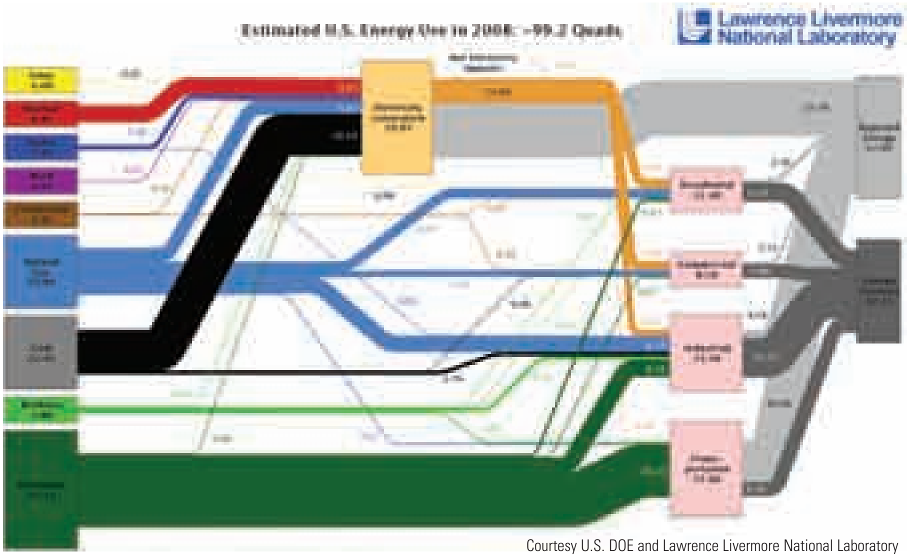
The ratio of energy services to the total amount of energy used is a measure of the country's energy efficiency. The remainder, explained Simon, "is simply rejected. For example, some rejected energy shows up as waste heat from power plants."

"I'm really excited about the renewed push for energy efficiency in this country," he said. "Because once that energy is rejected, it's no longer useful.

But more-efficient power plants, automobiles, and even lightbulbs really do reject less energy while providing the same energy services."

Lawrence Livermore National Laboratory has helped to visualize the Energy Information Administration's U.S. energy data since the early 1970s. Founded in 1952, Lawrence Livermore National Laboratory is a national security laboratory, with a mission to ensure national security and apply science and technology to the important issues of our time.

Source: Lawrence Livermore National Laboratory • www.llnl.gov



Courtesy U.S. DOE and Lawrence Livermore National Laboratory

Renewables Hit New High

According to the latest issue of the "Monthly Energy Review" by the U.S. Energy Information Administration, production of renewable energy for the first third of 2009 (i.e., January 1 through April 30) was 6% higher compared to the same period in 2008. In April 2009 alone, renewable energy sources accounted for 11.1% of domestic energy production and exceeded the amount contributed by nuclear power.

More specifically, domestic energy production for the first four months of 2009 totaled 24.394 quadrillion Btu (quads) of which renewable sources (biofuels, biomass, geothermal, solar, wind, and water) accounted for 2.512 quads. In April 2009 alone, though, total U.S. energy production was 5.980 quads with 0.664 quads (11.1%) coming from renewable sources; nuclear power provided .620 quads (10.4%).

Fossil fuel use is dropping sharply, and nuclear power is essentially stagnant while, month after month, the mix of renewable energy sources continues to set ever-higher records.

For the first four months of 2009, U.S. renewable energy production included hydropower (34.6%), wood and wood wastes (31.2%), biofuels (19%), wind (9.3%), geothermal (4.7%), and solar (1.2%). Most of these sources grew compared to the first third of 2008, with wind expanding by 34.5%, biofuels by 14.1%, hydropower by 8.2%, and geothermal by 2.6% The contribution from solar sources remained essentially unchanged while wood and wood-waste energy declined by 4.9%.

Total U.S. energy consumption fell 5.7% during the first four months of 2009 compared to the same period in 2008 with fossil fuel use accounting for almost the entire decline.

"As Congress continues to debate energy and climate legislation, it would do well to take note of the clear trends in the nation's changing energy mix," said Ken Bossong, Executive Director of the Sun Day Campaign. "Fossil fuel use is dropping sharply, and nuclear power is essentially stagnant while, month after month, the mix of renewable energy sources continues to set ever-higher records."

Source: Sun Day Campaign • www.sun-day-campaign.org

Efficiency Rules

Energy efficiency has remained America's cheapest, cleanest, and fastest energy source for five years running. At least that's the conclusion of a new study from the American Council for an Energy-Efficient Economy. The study—"Saving Energy Cost-Effectively: A National Review of the Cost of Energy Saved Through Utility-Sector Energy Efficiency Programs"—shows that the utility cost per kWh of energy efficiency has held steady or even slightly declined at about 2.5 cents over the last half decade, even as the costs for new coal, nuclear, and other supply-side energy alternatives have risen. In 2008, pulverized coal cost between $0.07 and $0.14 per kWh; combined-cycle natural gas cost between $0.07 and $0.10 per kWh; and wind electricity cost between $0.04 and $0.09 per kWh.

Source: KleanIndustries • www.kleanindustries.com

PV Modules: It's a Buyer's Market

A massive oversupply of PV modules, combined with slowing global demand for large-scale projects, has forced PV manufacturers to lower prices to unload backlogged inventory.

In 2009, one out of every two modules will not be installed but rather stored in inventory, according to industry analysts at the market research firm iSuppli Corp.

For now, consumers are reaping the benefits. According to Solarbuzz, overall industry average suggested retail prices have fallen since the end of 2008, down to about $4.38 per watt. They are expected to continue declining into next year, according to Thomas Maslin, a senior analyst for Emerging Energy Research, a consulting firm. Last summer, one respected brand of UL-listed crystalline module dipped below $3 per STC-rated watt, retail street price.

"For homeowners, it's a great time to invest in solar; the best time in a long while."

Manufacturers of balance-of-system equipment are also expected to lower prices. Increased competition and larger scales of production to meet demand also will contribute to lower system costs.

Lending to favorable market conditions in the residential sector is the recently expanded federal tax credit, which offsets up to 30% of the system cost and is no longer capped at $2,000. While federal tax credits are expected to stay in place, state and local programs have begun to decrease their payouts as a result of lower overall system costs, lowering the potential system savings overall.

But Glenn Harris, chief executive officer of SunCentric, a solar consulting group, says, "For homeowners, it's a great time to invest in solar, the best time in a long while. Consumers are jumping at the chance to go solar, taking advantage of lower prices to get the solar-electric systems they have wanted but could not afford until now."

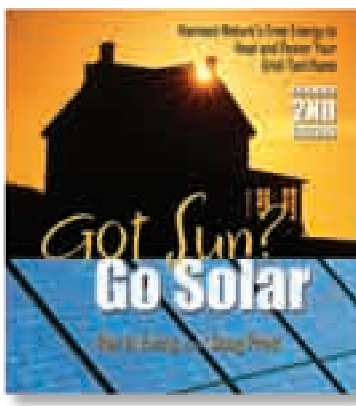
—Michael Welch & Kelly Davidson

MEDIA

Got Sun? Go Solar!

Rex A. Ewing and Doug Pratt (PixyJack Press, 2009)

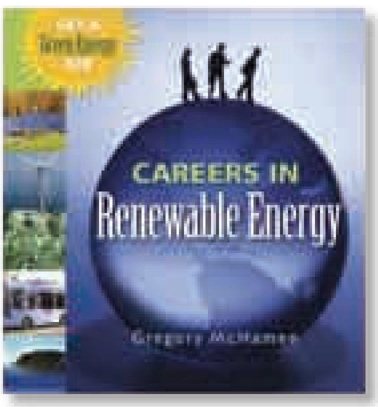
Know someone who is thinking about implementing solar technologies at their home? This updated version of an old favorite is a bookshelf-must for any budding RE practitioner. Authors Ewing and Pratt cram nearly three decades of firsthand RE wisdom and technical know-how into this easy-to-read paperback. Retaining the successful format of the first edition, the text is revised to include the latest advances in the field. The book covers battery backup versus batteryless systems, as well as equipment needed and installation considerations. New sections cover solar space and water heating, and geothermal heating and cooling. Other topics include legal and safety issues, incentives and rebates, and permits and paperwork. A lengthy appendix provides state energy offices, system sizing worksheets, and much more.



Careers in Renewable Energy

Gregory McNamee (PixyJack Press, 2008)

Want to give someone a leg up in seeking a rewarding career in renewable energy or green building? This handbook explores the many job opportunities available and offers tips on how to break into the field. Each chapter provides an overview of the different job sectors and career paths, complete with salary information and education requirements. The sectors covered include: solar and wind energy; biofuels; hydrogen energy and fuel cells; geothermal energy; hydro energy; green building; climate study; and energy management and efficiency. An extensive appendix features a list of schools, workshops, and training programs, as well as professional associations and job-search Web sites.



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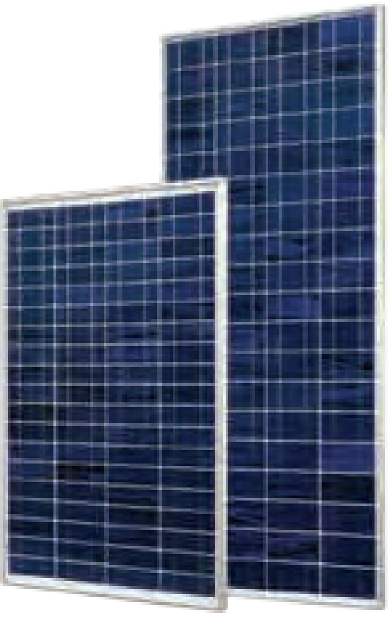
Evergreen Solar ES-C Module with J-Box

In the fall of 2009, Evergreen Solar (www.evergreensolar.com) began offering the ES-C series PV modules. They are designed to maintain high-enough voltages for battery charging, even under high-temperature conditions, making them well suited for off-grid applications. These modules are offered in 70-, 80-, 110-, 115-, 120-, and 125-watt models, and each module contains two bypass diodes, helping reduce energy loss from partial shading.

Evergreen's new modules feature J-box terminals rather than plug-in connectors and leads, allowing the use of conduit between modules. This is a requirement for accessible arrays with maximum system voltages of more than 30 V per the *2008 National Electrical Code*'s Article 690.31(A).

Modules feature multicrystalline string-ribbon solar cells, which Evergreen says have a 12-month energy payback.

—Justine Sanchez



Courtesy www.evergreensolar.com

Blue Oak PV Products Disconnecting Combiner Box

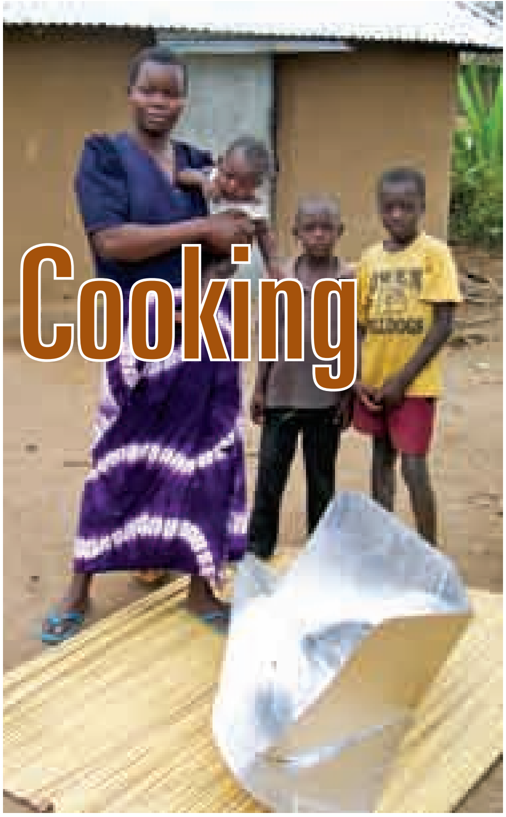
Courtesy www.blueoakpvproducts.com

Blue Oak PV Products (www.blueoakpvproducts.com) has introduced an ETL-listed (to UL Standard 1741) disconnecting solar combiner box. This allows installers to combine series strings and de-energize arrays at the array location without having two separate enclosures. The disconnect switch has lockout capability and is load-break rated to prevent the arcing from disconnecting high-voltage DC sources, like strings of PV modules.

The disconnecting combiner is rated at 600 VDC and comes in 8-, 16-, and 24-pole versions. The 8-pole version has a maximum continuous DC output current of 100 A, and the 16- and 24-pole versions are rated at 150 A. Both the 8- and 16-pole versions can be ordered with either a fiberglass or steel enclosure, and the 24-pole combiner has a steel enclosure. The positive bus and terminals are covered with a clear, rigid-plastic cover to prevent accidental contact.

—Justine Sanchez

The Power of Solar Cooking



Cooking a multi-pot meal on a four-burner range or reheating last night's leftovers in the microwave are conveniences that most of us take for granted, and it's easy to forget that not everyone has such amenities. For hundreds of millions of people around the world, cooking a meal or even just boiling water is a laborious chore.

The majority of families in developing countries live without electricity, gas, or utilities, and rely on open fires or stoves fueled by wood or dung to cook their food. Some families may have the "luxury" of a fossil-fueled burner or stove, but they end up spending much of their meager income on fuel, or having to trade a portion of what little food they have for fuel canisters.

In many places, women and children walk miles and spend between six and eight hours each day collecting fuelwood. As the perimeter of the resultant deforestation grows, the task becomes that much more time-consuming—forcing them to walk greater distances, and ultimately, leaving the family with little time to pursue other things, such as education and income-generating activities.

SCI Programs

Sunny Solutions (Kenya)—In partnership with local communities, SCI trains local women to make and sell solar cookers in three Kenyan communities. Since July 2003, 23 women have received training, and more than 3,000 solar cooker kits, including cooking and water pasteurization supplies, have been sold within the region.

Safe Water Project (Kenya)—SCI is working with the Kenyan authorities to increase water-quality awareness and reduce incidence of waterborne diseases. This two-year pilot project aims to introduce SCI's solar pasteurization package and community water testing kit to 20 communities in western Kenya.

Refugee Camps (Chad, Kenya, and Ethiopia)—With local and international agencies, SCI brings solar cooking skills and supplies to refugee camps in the regions. One survey showed that solar cookers allow refugee families to cut their firewood use by 27% and increase their food consumption by an average of four servings daily, since they are no longer forced to trade food rations for wood.

To learn more or support SCI's programs, visit www.solarcookers.org.
Donations allow SCI to provide families in Africa with solar cookers, training, and follow-up support.

The problem is compounded by health concerns. Smoky fires and poor ventilation contribute to respiratory diseases among women and children. And, because fuel and firewood shortages often make water boiling impractical, millions of people become sick and die every year from waterborne diseases.

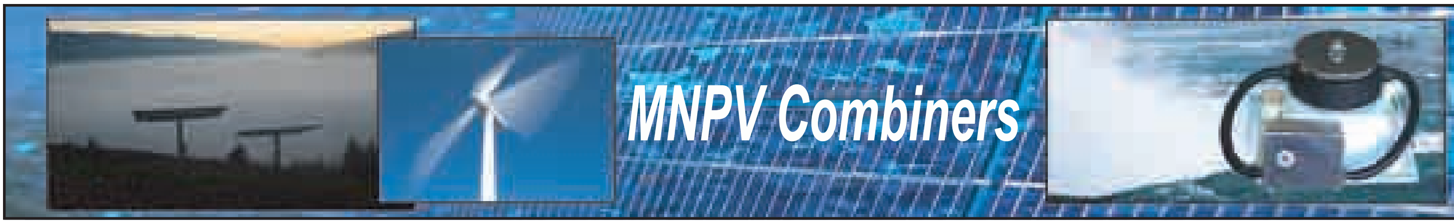
Solar Cookers International (SCI) is harnessing the power of the sun to help rural communities develop safer and more efficient ways of cooking. Since 1987, the Sacramento-based nonprofit has helped thousands of families in multiple countries to cook food and pasteurize water with simple solar cookers.

SCI's efforts are largely concentrated in eastern Africa, where the group has a satellite office, and conditions are prime for solar cooking. Through demonstrations at marketplaces, churches, and other public places, the group raises awareness of solar cooking and solar water pasteurization, and helps women develop and run solar cooking businesses in rural communities.

Key to SCI's program is its signature "CooKit" solar cooker, which is distributed with a black pot and oven roasting bags. For water pasteurization, the CooKit is paired with a water storage container and a reusable water pasteurization indicator that helps users determine when water has reached pasteurization temperatures. The group also has developed an easy-to-use, inexpensive laboratory kit that allows communities to test local water sources for 25 contaminants.

The group's "integrated cooking" approach encourages the use of solar cookers when the sun is shining but also promotes more efficient methods for fuel-based cooking. One of the more popular methods is the use of simple baskets or boxes lined with straw, sawdust, or blankets. Much like a Dutch oven, these baskets keep food warm and even allow food to continue cooking after being removed from a heat source, thereby reducing the amount of fuel or firewood necessary.

—Kelly Davidson



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Wild About Solar
at Salt Lake City's Hogle Zoo Hospital

Courtesy Ken Gardner (2)

In 2009, new arrivals at Salt Lake City's Hogle Zoo included a snow leopard cub, two golden lion tamarinds, an elephant named Baby—and 21 kilowatts of PV modules at the zoo's animal health center.

The LEED-certified hospital facility is the second zoo facility with solar-electric modules. A year ago, a 15 kW array was placed on the Elephant Encounter building. The zoo's efforts to "go green" will also include an educational kiosk to educate the public about renewable energy.

For this project, the main challenge was to avoid array shading from the HVAC units. Existing rooftop components and obstructions were mapped using a robotic surveyor. The rooftop layout was then plotted in three dimensions using ArchiCAD, a computer modeling program. Modules were then placed in the model to evaluate potential shading. Modeling permitted the best possible use of space considering not only shadows, but HVAC equipment access and trip hazards from system conduit. The assessment revealed the best location to place the array and limit shading during the peak solar window.

Ninety-nine 215-watt modules were installed in three series strings, with 33 modules for each inverter. The racks were custom-built using standard strut, fittings, and cinder-block caps, and engineered to withstand a 90 mph wind speed. Strut components also act as built-in wire gutter, conforming to *NEC* 384, which satisfies *NEC* 690.31 (A), a requirement that stipulates placing readily accessible circuit conductors in raceways rather than "zip-tied" to rack components.

The installation went on-line this fall, with production anticipated to meet about 30% of the hospital's electricity needs. Along with its PV system, the hospital also uses natural lighting through well-placed windows to reduce the need for artificial lighting, and passive solar to offset some mechanical heating. The zoo has an aggressive plan for modernization that will continue to include renewable and sustainable energy projects.

—Ken Gardner

PROJECT: Hogle Zoo Hospital

System: Commercial grid-direct PV

Installer: Gardner Engineering, www.gardnerengineering.net

Date commissioned: September 2009

Location: Salt Lake City, Utah, 41°N

Solar resource: 5.3 average daily sun-hours

Array size: 21.3 kW STC

Average annual production: 31,000 kWh AC

Average annual utility bill offset: 30%

EQUIPMENT SPECIFICATIONS

Modules: 99 REC SCM-215, 215 W STC

Inverters: Three, SMA America Sunny Boy SB7000US

Array installation: Custom-built, ballasted rack on a flat PVC membrane roof; oriented at 182° azimuth

Determining Average Wind Speed

Courtesy Ian Woofenden (2)

If you want to make an intelligent estimate of how much energy you can make with a wind generator, you must have a good idea of your wind resource. For the purposes of home-scale systems, the wind resource is measured as an average wind speed. For residential sites, the highest average wind speed is about 14 mph—much lower than you might predict.

An average wind speed is not your casual observation of "it always blows 20 mph" or "I saw it blow 55 mph once." It's not an instantaneous wind speed, but an average of all the winds your site gets. And it's not something that can be observed. It needs to be measured.

The average wind speed needs to be measured at the proposed wind generator's "hub height." It's crucial to get an accurate number, because the relationship of energy potential to wind speed is cubed. You'll likely have only a 3 to 6 mph average wind speed just above your rooftop, but you might have a 10 mph average on a 100-foot tower that's 40 feet above the tallest trees. The difference in energy potential between 10 mph and 5 mph is eight to one.

The average wind speed needs to be measured at the proposed generator's "hub height."

So how do you obtain this hub-height wind speed at your property? Unfortunately, it's not usually easy to come by. If we were surveying sunshine, we could consult tables, check the shading, and come up with a number of "peak sun-hours" available. This number is the solar equivalent of an average wind speed. But with wind, it's not so easy.

- The best strategy is to measure the wind speed at hub height for a year or more. This is what wind farmers do, and it's the only way to get a completely accurate measure of the average wind speed on your specific site. The drawbacks are cost and time: Homebrew methods of setting up an anemometer may drop the cost to between $1,000 and $2,000, depending on the tower height needed. A professional setup will likely cost three to five times that (or more).

- Use local data. Sources include other wind energy users, weather bureaus, airports, newspaper historical weather data, and local weather enthusiasts who have their own monitoring stations and keep tabs on other local data. Mapping the data you have, plus characterizing similar sites, may give you some idea of your resource.

- Professional wind mapping (found at www.awstruewind.com and other sources) is used by wind farm developers. This method is based on existing data and modeling, and can be a fairly accurate way to estimate real-world values. However, this data is developed for much taller towers (60 to 100 meters), and must be scaled down to home-scale system heights using a tool like the one at www.greenjury.com/shearcalc.php.

- Without access to objective data, using more subjective resources becomes better than nothing. One common method is gauging wind speed by the deformation of coniferous trees, as quantified by the Griggs-Putnam wind energy index. Interviewing longtime locals for anecdotal comments about the winds in the area is very low on the list of quality methods, but not entirely useless, since it may deter you from trying to capture wind energy at a poor site.

In the end, it's best to use all available methods, take an average of the results, and then round down. It's much better to predict lower wind speeds and be pleasantly surprised than to predict unrealistically high wind speeds and be disappointed.

—Ian Woofenden

SOLAR-POWERED WHEELS FOR KIDS

My grandson Evan wanted to build a solar-powered car. We bought a used Jeep Power Wheels by Fisher-Price to save time. By adding a 20-watt PV module, crash bumpers on the module, a charge controller, and a volt meter, we made a solar-powered car that can be driven all day. At the California Center for Sustainable Energy's Street Smart event, which featured the new Tesla, Prius, and Honda Insight, we let the kids ride in miniature solar-powered Jeeps. They drove the cars non-stop.

Courtesy Barry Butler

We have now converted five Power Wheels Jeeps and use them at educational events to help kids understand solar energy. The batteries stay charged when the Jeeps are parked in the sunshine (and the kids do not use them). When the kids are ready to drive, the solar-powered Jeeps are charged and ready to go.

Barry L. Butler • Butler Sun Solutions

OFF-GRID APPRECIATION

I loved Allan Sindelar's article on off-grid planning ("Toast, Pancakes & Waffles: Planning Wisely for Off-Grid Living" in *HP133*). My husband and I are planning to go off the grid this fall. We recently moved back to the Four Corners area to our farm, where we are going to build our dream green home. For the short term, we have to live in our very inefficient mobile home until we finish construction.

The estimate to tie to the tribal utility grid was $10,580, which was shocking. So we said, "Why not just spend $15,000 and buy our own system—and never have to pay anyone for electricity?" Easier said than done…

We recently added a little one to our family, so there are three of us who will be living in this home. We have planned this move for the past three years while trying to learn everything we can about solar anything. It never seems enough.

Your article helped me to see what I need to do. Now I know I will definitely need a propane tank for our heating, cooking, and hot water. I am shopping for a big tank because I want plenty of hot water, heat, and hot food.

It's funny—we live between two power plants, and we are going solar. My husband works for an oil refinery and I work at a coal mine, and we are going solar.

Thank you so much for your valuable information—you saved us from freezing.

Yolanda Littletree • Nenahnezad, New Mexico

EFFICIENCY EDUCATION

Courtesy Lindsey Roke

Doug Stevens is looking for some simple efficiency examples that even young children can understand ("Efficiency & Solar Education Ideas" in *Ask the Experts*, *HP132*). I work for an appliance manufacturer (Fisher & Paykel) in New Zealand. Our washing machines have highly efficient, brushless permanent-magnet motors. When old machines with these "smart-drive" motors come through our recycling facility, we collect the motors and supply them to a company (www.ecoinnovation.co.nz) that gives them second lives as alternators for wind or water turbines.

The company gave us a unit that they had fitted with a crank handle. They set it up to power either or both of two individually switched desk lamps. One lamp has a standard incandescent bulb while the other has a compact fluorescent. We all know that the CFL uses about 25% of the energy of the other. But I have yet to see anybody, experienced engineers included, who really has a good feel for what that means—until they tried cranking the handle while somebody else flicked the switches. Doug would find that such a demonstration would be a very effective way of really getting the message across, to any age. The photo shows George Gray, our recycling facility manger, trying out the demonstration unit.

Lindsey Roke • Fisher & Paykel

SOLAR HURDLE

I have just finished reading the article on calculating PV return ("Money Matters: Does an RE System Make Economic Sense?" by Dan Chiras and Don Richter in *HP131*). I appreciate the different methods of proving PV to be a good investment and look forward to using some new ways to share the long-term investment that a PV system offers with my clients.

Here in Hawaii, I have been experiencing a hurdle that I can't seem to get over on the commercial side of the PV industry. I work with many Associations of Apartment Owners (AAOs) that are interested in installing solar energy to help relieve some of their common-area electrical costs. They can easily see the benefits of installing solar hot water systems on buildings that have hot water usage (laundry rooms, etc.), but are timid about investing money when considering buildings that only need PV.

One primary problem is that the AAOs have no tax liability because they are nonprofit organizations. Therefore, they cannot receive the 30% federal nor the 35% state tax credits.

So my question is whether *Home Power* (or any of its readers) is aware of other ways to make a PV investment attractive to those without tax liability. I would appreciate any advice, recommendations, or referrals.

Alex Thomson •
Hawaiian Island Solar

ELECTRIC TRIKE

Courtesy Denny Markley

It all started when my 75-year-old mother-in-law wanted to ride the 12-mile-long bike trail with my 10-year-old son last summer. I bought a six-speed adult tricycle with 24-inch wheels. After assembly, I took it for a ride and found it to be difficult to pedal—much harder than an ordinary bicycle.

An electric motor assist would have been of great help to my mother-in-law, but no motorized vehicles are allowed on the trail. After some searching on the Internet, I discovered the Federal Electric Bicycle Law, HR727, which states that a two- or three-wheeled bicycle with a 750-watt (1 hp) electric motor or smaller that travels at 20 mph or less is not considered motorized.

Next, I had to do some math to fit the motor to the 24-inch tricycle and keep the speed in check. You can use this formula for any size wheel or motor—just substitute your numbers into the calculations. Using a 24-inch (2-foot) diameter wheel: *pi* times 2 feet (3.14 x 2) equals 6.29 feet per complete turn of this wheel. Dividing 5,280 feet in a mile by 6.29 feet equals 839 complete turns in one mile. If you want 20 miles per hour, you'll have 16,780 revolutions (20 x 839) in one hour. Now divide by 60 to convert revolutions per hour to revolutions per minute (16,780 ÷ 60), which equals 280 rpm needed for this wheel to go 20 mph.

My motor is a 24 VDC, 3,000 rpm, 1 hp Scott, so the reduction to get the maximum speed I wanted was just about 11 to 1. I attained this reduction in two steps, using a belt as the primary and a #35 roller chain as the final reduction.

I bought two 12 V, 50 Ah batteries to power it, and a thumb throttle for the 275 A motor controller. What a ride! The torque is amazing. From 0 to 20 mph, it would keep up with most motorcycles. Also, it does not slow down on hills. I have not fully tested the range yet, but I expect it to be about 75 miles—more if you pedal along and add your 100 to 250 W of human power. When gas hits the $4 mark again, I might be riding this to work…

Denny Markley •
Canfield, Ohio

ERRATA

The string inverter specifications table published in *HP133* listed Power-One and Magnetek as co-manufacturers of the Aurora line of string inverters. The Aurora PVI-3.0, 3.6, 4.2, 5000, and 6000 string inverters are manufactured by Power-One.

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Ask the EXPERTS!

Wind Force

I'm trying to calculate the force the wind will exert on a 6-meter-diameter wind turbine, to design a tower. I see that a wind speed of 80 kilometers per hour would exert a force of 279 kilograms per square meter (on a flat surface), but I have no idea as to how this relates to blades on a wind turbine. Can you tell me how to go about that calculation?

John Meyer • Midland, Ontario, Canada

You can use those surface pressure calculations to determine the wind loading on the tower itself, but the wind turbine blades are not at all like a static flat surface. The blades fly across the wind like the wings of a plane, generating a lift force that pushes back at the airflow and slows it down. Slowing the wind extracts its energy and drives the turbine. It's possible to calculate the ideal amount of force to achieve this goal, but the reality is likely to be different, so it's advisable to include a healthy safety factor.

When the wind gets stronger than necessary for full power, the turbine will have to protect itself by one of a number of possible strategies that also affect the thrust loading. For example, some turbines will stall their blades. This spoils their ability to capture energy, but it may not reduce the thrust very much. Others yaw sideways to the wind, dodging its force, but it takes time to yaw, and so a gust can create a high peak thrust.

If the turbine were still converting wind energy into electricity in 80 kph winds (50 mph; 22 m/s), it might produce up to 50 kW. The ideal thrust would be about 132 kg per square meter, approximately half of the figure you quote, adding up to 740 kg over the area of the rotor. It's unlikely that the turbine would be designed to work like this. It's more likely that it would start to furl or govern at about half of this wind speed, when the thrust would only be one-quarter as much. The actual working thrust could be around 180 kg, but for various reasons, the peak thrust would be quite a bit higher. Therefore, it would be wise to apply a safety factor of perhaps five times to that, which yields a nominal peak thrust closer to 1,000 kg of force for the purpose of tower design.

Designing a tower is really a job for an engineer. The calculations are based on the highest wind speed that the tower will experience. They include an element of wind thrust on the tower itself and also the thrust on the turbine. The critical load on the tower is usually the bending load at the highest supported point. For a guyed tower, this is the top guy level. For a freestanding tower, the bending load is at ground level. Bending moment is the force multiplied by the radius of action, so tall towers without guys need to be very strong. It's wise to also factor in the gyroscopic moment that arises when the turbine yaws sharply around the tower top in turbulent conditions. The force calculations can also reveal the tension in the guys and the uplift forces on the anchors. In many cases, the designer will consider the natural frequencies of the tower in relation to the speed of the blades so as to avoid resonances.

Hugh Piggott, Scoraig Wind Electric • Scoraig, Scotland

Courtesy www.venteraenergy.com

A Ventera VT10, 22-foot-diameter wind generator on a Rohn tower engineered for the maximum wind load it will receive.

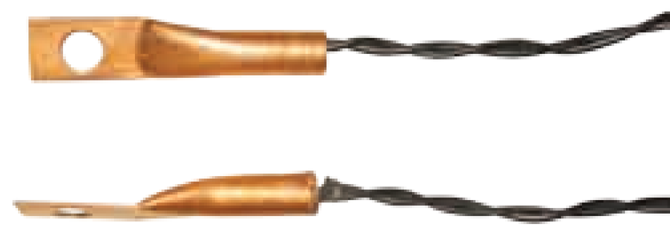
"Designing a tower is really a job for an engineer. The calculations are based on the highest wind speed the tower will experience."

Thermal Sensor Placement

For a solar thermal system, where should the collector sensor be located? Older collectors had a dry well for the sensor in the hot pipe coming out of the collector. However, the collectors used in my recent installation don't have these wells. Instead, a 10K sensor was strapped onto the collector's output pipe.

I would expect that monitoring the heat would be quicker. Our six-collector glycol system has a 300-gallon storage tank with another sensor at the bottom. Two pumps feed a plate exchanger.

David Miller • via e-mail



Courtesy Chuck Marken

In any solar hot water system, we want one sensor to measure the temperature of the hottest fluid coming out of the collector(s). Most sensors are thermistors that vary their electrical resistance with changes in temperature. They are encapsulated in a 1- to 1.5-inch-long, 1/4-inch-diameter copper tube. The tube sometimes has a flattened end, which should be attached to the pipe it is measuring with a hose clamp, assuming copper tubing is used on the collector loop.

Securely clamping the sensor to the collector's hot outlet pipe—and as close as possible to the collector edge—will help the sensor accurately measure the temperature of the hot fluid. The sensor should be well insulated.

Although it would seem that a sensor immersed in the fluid would be more accurate, this isn't necessarily the case. The combination of the relatively low thermal conductivity of the collector-loop fluid and the thermistor encapsulate (plus the thermistor's accuracy) makes an immersion sensor unnecessary for the accuracy of the differential control. However, an immersion sensor can increase accuracy if the piping is some type of plastic with low conductivity.

Chuck Marken • *Home Power* Solar Thermal Editor

Importing Solar Gear

I recently began teaching a class on weekends at the Bronx Community College on off-grid and grid-backup systems, with emphasis on systems for international locations. Many students in the class (mostly from Latin America and Africa) are interested in purchasing renewable energy system components that can be used in their home countries. Several in particular have asked for contacts for distributors.

I'm wondering if you have any basic information I could share with the students about the ease (or difficulty) and costs of importing RE components into such countries as the Dominican Republic, Peru, Brazil, Nigeria, and Senegal. I imagine that every nation has its own set of tariffs and complicated rules. Do you have any literature that would help explain them?

Jim MacDonald, Solar Energy Systems • Brooklyn, New York

Import-export rules and regulations vary country by country. Unless individuals are importing to their country as a regular part of business, little incentive exists to try this for one project. Importing gear for the purpose of a single system will likely be more trouble and cost compared to buying equipment locally. The lessons learned in the one-time transaction will be far more expensive than purchasing though an established local supplier who already knows the best way to move freight, clear customs, etc.

Most longtime international clients in the renewables industry have established relationships with freight forwarders who have operations both in the United States and their home country. I view this scenario as a win-win situation—my responsibility is to ship to the forwarder warehouse in the United States and the customer has direct contact with the forwarder from that point on.

It is most efficient for customers to use their own regular forwarder for all equipment, otherwise they will always need to go through their U.S.-based supplier to get the information they need on a particular shipment. Encourage those students who are going into the RE business to establish relationships with trustworthy freight forwarders who have experience shipping to their respective countries.

Dean Middleton • SunWize Technologies Inc.

"In any solar hot water system, we want one sensor to measure the temperature of the hottest fluid coming out of the collector(s)."

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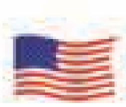

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Batteryless or Battery-Based?

I am interested in installing a grid-tied PV system on my home. I would like to keep installation costs down and was hoping to install a batteryless system first and then add battery backup at a later time.

> **"There is no single-inverter system that can be switched between a battery-based system and a batteryless system."**

I recently heard from a dealer that this was not possible without changing inverters (at the minimum). Of course, I assume that a controller would need to be added, but is it true that there is not an inverter that could be interfaced with the grid and also accommodate power from a battery bank?

Tom Craig • Asheville, North Carolina

This is a one-or-the-other choice to make. There is no single-inverter system that can be switched between a battery-based system and a batteryless system (though I recently saw a prototype inverter designed to do this very thing). About the best you could do to meet your needs would be to invest in the battery backup equipment up-front, but with only the minimal battery bank as sized in the inverter specs. Later, you could expand the battery bank if your backup needs require it. However, most in your situation would just start with the full-sized battery bank.

Keep in mind that the inverter and balance-of-system equipment for a battery backup system will cost about twice that of a batteryless system. Installation costs will be greater too. And you'll have the ongoing cost of battery maintenance and replacement, plus somewhat lower efficiency from the system over its lifetime.

If you install a modern batteryless inverter now, when you want to switch to a battery-based system later you will likely be able to

recoup about half of the inverter price by selling it used. Switching to a battery-based system later may require rewiring the PV array to meet different voltage requirements. Batteryless inverters generally work at high DC voltages (up to 600 VDC), whereas battery-based systems work at lower voltages (typically 24 to 48 VDC).

It is possible to design a *multiple* inverter solution that would meet your goal of starting out with the batteryless inverter. In the future, that inverter could be "AC-coupled" with a battery-based inverter that would work in conjunction with your existing system—without having to rewire your array. However, these systems are significantly more expensive and complex. (See "The Switch from Urban to Rural" by Kelly Davidson in *HP133* for an example.)

Regardless, work with your installer to make sure that the PV array is the right size for both systems, and that it can be rewired if necessary to be used with the new application.

Michael Welch • *Home Power* Senior Editor

Battery Spill

A friend of mine has an ancient off-grid system (now out of commission), with two L-16 batteries. I assume that the two L-16 batteries self-discharged over time, then froze, cracked, and spilled all the electrolyte into the rubber containment tub. Amazingly, it seems to have held there.

What is the best way to clean this up? How do I neutralize the acid before trying to do something with it? With baking soda? How much neutralizing agent would be required? Will it foam up like a science-fair volcano exhibit? Even once neutralized, I assume that I can't just dump it into the woods. What then?

Ben Branch • Newdale, Idaho

Put on your old clothes, goggles, and gloves, and use baking soda (sodium bicarbonate) to neutralize the spilled electrolyte. Get a case of it, because you will need more than 10 pounds to neutralize the amount of acid contained in two L-16s.

The acid will foam up grandly when the soda is added, so add it slowly. Once the reaction is complete, the neutralized acid can be composted, since the resulting chemicals (sodium bicarbonate and sodium sulfate) are benign—the rest is mostly water.

Take the broken battery cases to a battery dealer for recycling. The lead in the cases *is* dangerous to the environment, and worth a buck or two.

Richard Perez • *Home Power* Publisher

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Less Rack, More Solar
PATENTED

GREENING the neighborhood

by Kelly Davidson

Courtesy www.plymouthenergy.org

A PAREI "energy raiser" crew (with codirector Peter Adams, second from left) takes satisfaction from another successful solar hot water system installation.

In 2003, after reading *The Party's Over*, Richard Heinberg's startling revelations about the coming depletion of the world's oil reserves, New Hampshire advertising executive Peter Adams answered the call to action. He started by bringing a group of like-minded friends and neighbors together just to talk about what he'd learned. The prospect of an energy crisis struck a chord among residents who rely on oil to heat their homes through the long winters, and pay thousands of dollars each year for heating. Discussions during those potluck dinners soon evolved into finding ways to help each other prepare for the inevitable crisis.

From those humble beginnings came the Plymouth Area Renewable Energy Initiative (PAREI). Adams, who had practically no experience with RE systems, was inspired by the do-it-yourself projects he'd read about in *Home Power*, and enlisted friend Sandra Jones to help get the organization off the ground. Jones put her experience with nonprofit management and community organizing to work. Within 10 months of incorporating PAREI as a tax-exempt nonprofit in 2004, she secured a $35,000 grant from the U.S. Department of Energy that enabled the group to hire her as a part-time administrator and open an office in Holderness, New Hampshire.

Solar Supplemental Heating

One of the group's more complex energy raisers took place at the home of Kevin Frank and Caryn McHose in Holderness, New Hampshire. Increasing propane costs motivated the couple to integrate solar thermal into the existing radiant floor heating in their 2,000-square-foot house and the 1,700-square-foot adjacent studio, which houses the couple's body-movement and therapy practices.

Frank turned to PAREI for guidance and supplies. Even though he did not have any previous experience with solar hot water, he was well versed in energy-efficiency techniques from his years as a professional builder and felt confident that he could complete the first phase of the project on his own. And, since there were no rebates available through the local utility at the time, working with a licensed installer—a requirement to receive most rebates—was not necessary.

In addition to adding a wood-fired boiler to the heating system, he installed three Sun-Earth flat-plate solar thermal collectors on the house's roof. Hot water from the collectors is routed into a concrete storage tank in the basement. Laying the groundwork for the second phase, Frank also constructed a concrete storage tank in the studio basement and laid the underground, insulated PEX loop between the two buildings. The two original propane backup boilers were kept to provide supplemental heating, if needed.

For the next phase, Frank called on PAREI and signed on for an energy raiser. Three, 30-tube Apricus collectors were installed on the studio roof, piped to heat exchangers and pumps in the basement storage tank for domestic water and space heating. Prior to the day, Frank and a few other members installed the heat exchangers in the tank and plumbed to the tank. They also installed some staging on the roof and built a mount from pressure-treated lumber for the Apricus. The rest—installing the collectors and rack, finishing the plumbing, and configuring the controls for the system—was tackled by a 25-person crew that turned out for the day.

Frank estimates that the first phase—including the tanks' construction, wood boiler assembly, trenching, and Sun-Earth system—came to more than $17,000 after the federal tax credit. Thanks to the discounts and free labor through PAREI, the cost of the second phase was considerably less. The Apricus system for the studio totaled $3,909 after state and federal rebates.

Frank says the time, energy, and investment was well worthwhile, and credits PAREI for empowering him to tackle the project. Today, the couple's propane dependency is down from 800-plus gallons to roughly 50 gallons per year—most of which is used for cooking, clothes drying, and some intermittent space heating in the studio's second floor, which is not equipped with radiant floor heating. During cloudy spells, Frank stokes the fire in the wood boiler as his first line of defense and, only when necessary, kicks on the two original propane-powered water heaters for backup.

"PAREI changed the way we use energy, and the group is truly revolutionizing this little part of the granite state," Frank says. "Knowing that wood and solar are the primary sources for both the space heating and domestic hot water makes it easier for me to turn up the heat, and make our clients and family more comfortable."

At a time when state and local programs for RE were lacking, the initiative set out to provide area residents and businesses with access to the resources and education they needed. "It was a very different atmosphere a few years ago," says Adams. "The state was not very supportive nor was the infrastructure in place for people to readily get solar, so we decided we had to take matters into our own hands." The group started by focusing on solar water heating, since several members had some basic knowledge of those kinds of systems.

Cooperative Learning

"We were not experts in renewable energy, and we were learning right alongside of our members. We ended up educating each other, reading books, taking classes, and then sharing what we'd learned at our meetings," Jones says.

"Once word got out about what we were trying to do, people came out of the woodwork to share what they knew and to learn from others. Homeowners, electricians, property managers, carpenters, and plumbers all had something to contribute, and before long, we had members helping members build wood boilers and develop plans for homemade solar water heating setups," she adds.

The group's mix of community-mindedness and moxie has proven to be a winner. In just a few short years, its

PAREI volunteers gather for an end-of-the-day celebration after their thirty-second energy raiser.

Courtesy www.plymouthenergy.org

In barn-raising style, PAREI members flock the roof of Kevin Frank's studio to help install 90 evacuated tubes.

membership base has grown to include more than 300 families and businesses, and the group has hired two additional part-time staffers. And, while the state's new incentive programs and progressive net-metering laws have helped further its cause, PAREI has won recognition from both state and federal government agencies for its role in transforming the area's virtually nonexistent RE market into a burgeoning solar economy.

To date, PAREI has coordinated or assisted with 115 PV and solar thermal installations, with nine more scheduled for the coming year. As a result of their influence, regional technical schools now offer classes in solar thermal and solar-electric installation. Local hardware stores also expanded their inventory to include some supplies frequently required for solar energy installations and energy-efficiency upgrades.

Neighborly Savings

Key to PAREI's success has been its neighbors-helping-neighbors approach, modeled after the community tradition of an Amish barn-raising. At "energy-raiser" events, teachers, students, tradespeople, and homeowners alike gather for a day of work and socializing to install a solar hot water (SHW) system.

By working together, they accomplish what no single homeowner could do alone. The labor provided by volunteers translates to thousands of dollars in savings. Plus, through PAREI, the installation satisfies the requirement for state and federal rebate eligibility. PAREI reduces the costs even further by buying collectors in bulk and selling them to members at a discounted rate. The group also stocks several system components that are not readily available at the local retail outlets.

But the savings do not end there. The typical SHW systems, which supplement the homeowners' existing water heating systems, can reduce an average household's water heating bills by 60 to 80% and offset up to 4,000 pounds of carbon emissions per year. Adams estimates that his SHW system, installed as part of PAREI's inaugural energy-raiser, saves his family of four 200 gallons of fuel oil per year.

PAREI's Process

For the Adams' installation, 27 volunteers, including curious neighbors and local tradespeople, worked together to mount the 22-tube collector on the roof and install a 45-gallon solar storage tank in the basement. Although Adams says this first energy-raising event was

Goop, Shake & Pass the Tube

The Apricus solar collectors used by PAREI have some unique installation requirements, as fully explained in their manual. The systems have a proprietary rack for the collectors, which is a straightforward assembly in most cases. The collectors are manufactured to be assembled in a modular fashion, allowing for easier installation and smaller crews compared to larger flat-plate collectors that typically require more hands and extra equipment to lift them to the roof.

After the rack is assembled, the header assembly is attached to the rack and the tubes are installed one at a time. Prior to the tube installation, the condenser at the top of the heat pipe in each tube is "gooped" with a heat-transfer paste supplied by the manufacturer. Each heat pipe contains a small amount of copper powder that helps heat transfer and provides protection from freeze damage. To ensure the powder is in the bottom of the heat pipe where it is needed, the tube is turned upside-down, and then right-side up and shaken, then inserted into the header. With several people involved in the installation, such as at an energy raiser or workshop, the tube may be passed hand-to-hand, like a bucket brigade, leading to a quicker installation. Anyone handling the tubes should wear gloves to protect from injury in the event a tube should break.

—Chuck Marken

"pure chaos," the work-team persevered. "By the end of the day, after many trips to the hardware store," he says, "the system started generating PAREI's first clean and renewable hot water."

Now the energy raisers are far more systematic, says Jones. Prior to the event, team leaders meet for a "setup night," at which time the solar storage tank is placed and the pipe layout determined. On the day of the event, volunteers are organized into five teams. A roof-and-ground team attaches the rack of evacuated tubes, overseeing the "goop, shake, and pass the tube" assembly line (see "Goop" sidebar). The solar pipe-run team installs the pipe from attic to tank, and connects the thermostat wire and differential controller. A tank team connects the pipe to the heat exchanger, and installs the pump and gauges. The attic team routes pipe through the roof, while the communications team stays on the ground to answer questions from spectators.

The complexity and scope of each system varies. Collectors have been mounted on roofs, walls, and the ground. The group has installed one- and two-tank systems, typically using 80- or 119-gallon solar storage tanks, but these systems tend to be too costly for the majority. Most often, homeowners choose a system with a smaller, 50-gallon solar tank to add to the home's existing water-heating setup.

The goop, shake, and pass-the-tube team at work.

Courtesy www.plymouthenergy.org

Solar Savings

When Amy and Todd Bickford built their new home a few years ago, they didn't put much thought into integrating solar technologies. "We knew we could not afford it at the time, so there wasn't much sense in exploring the idea," Todd says.

But after rising oil prices in subsequent years drove their heating bills to an "uncomfortable high," the couple considered the idea more seriously. They saw the potential in the southern exposure on their 5-acre property and wondered whether a solar thermal system could help reduce their dependency on the oil-fueled furnace.

"We have great solar exposure and didn't want all the solar energy to go to waste. Plus, it was frustrating to hear the furnace turn on in the middle of the summer when no one was using the hot water," Todd says.

With the economy taking a turn for the worse, Todd and Amy were hesitant to dip too deeply into their savings to cover the system cost. Even after state rebates, the up-front investment would still teeter on the higher side of what they'd hoped to spend.

Todd found the answer one morning while reading the local newspaper, which featured a story about PAREI. He attended a free informational session held during an energy raiser and says that they were "hooked after that."

"We loved the sense of community and how everyone came together to accomplish what one neighbor could not do alone," says Todd.

The couple volunteered at three energy raisers before their system was installed last May. In preparation for the event, Todd and a few PAREI volunteers disconnected the home's old water tank from the furnace and installed a new 75-gallon electric tank-style water heater. About 25 volunteers turned out for the installation, which was fairly straightforward but required some concessions on the part of the homeowners.

Partially bermed by a hillside, Todd and Amy's house features a walkout basement—making their home essentially three stories. The basement access made the tank installation easier but limited where the collectors could be placed, since PAREI prohibits volunteers from working more than two stories off the ground and would not permit volunteers to mount the collectors on the roof. Alternatively, the collectors were attached to the south-facing side of the house. This eliminated the need to run pipes through the roof but created another challenge—routing piping down the exterior siding into the basement. A quick brainstorming session gave way to a creative solution—disguising and protecting the pipe run with insulated gutters.

After the local utility rebate and federal tax credits, the system cost roughly $1,800. The couple expects the system to pay for itself in three to five years, depending on the price of fuel oil.

The Bickford home's SHW rack, almost ready to receive the evacuated tubes.

Homeowner Amy Bickford helps place the last evacuated tube, with help from energy-raiser volunteers.

How It Works

An annual membership fee (currently $55 per household, $75 per business, or $15 for low-income households) entitles a homeowner to either an energy audit or one solar site visit per year, where a staff member determines the feasibility of installing a solar thermal or solar-electric system. PAREI helps homeowners determine an installation plan that suits their needs—either hiring a professional installer, hiring PAREI's professional crew to assist with the installation, working with PAREI to learn to perform the installation on their own, or participating in an energy raiser.

"Most homeowners come out for at least one energy raiser, and then decide which way to go," Jones explains. "Some folks fall in love with the immediate gratification and community spirit of an energy raiser, while others get the confidence they need to go it alone. Then there's a good many that realize a hands-on approach is not for them and that they'd rather hire a professional. And that's alright—any which way they go about it, we've accomplished our goal."

Should a homeowner choose the energy-raiser route, they must first volunteer for at least two energy raisers prior to hosting their own—and then pay the favor forward at least twice afterward. The home must also undergo an energy assessment, where PAREI staffers and/or volunteers tour the home to determine ways to reduce the household's energy consumption and improve its energy efficiency. "This is an essential step," Jones says, "because we want to ensure that these systems reduce as much fossil-fuel consumption as possible."

While PAREI does not currently organize energy raisers for solar-electric systems, the group does refer homeowners to local tradespeople who provide members with competitive pricing. Many of these installers, Jones says, sought formal training and certifications as a result of PAREI's influence. For each referral, PAREI receives a small consulting fee, which helps offset the nonprofit's expenses.

Other PAREI activities include lectures and hands-on training for the general public. All told, PAREI represents a new model for "how to grow solar economies in communities," Jones says. "PAREI does more than just organize the energy raisers and provide the necessary volunteer labor. It brings communities together and illustrates the impact a committed group working hand-in-hand can have."

The group is now making it possible for other communities to replicate its model. Individuals interested in starting an energy initiative are welcome to visit PAREI in New Hampshire and participate in an energy raiser. For those who cannot make the trip, PAREI sells a CD-ROM and DVD "tool kit" that explains, among other things, how to organize energy raisers and rally community support. As part of the package, a PAREI member also serves as an advisor, providing start-up guidance via e-mail or over the phone.

Folks from Portsmouth, New Hampshire, signed on and used PAREI's model to create SEAREI (Seacoast Area Renewable Energy Initiative) and hosted its first energy raiser in August. The Renewable Energy Initiative of Portland, Maine, also got its start with help from PAREI and held its first energy raiser last March.

"It's been a very organic process since the beginning. We'd try something, and if it didn't work, then we'd move on," Adams says. "But we've learned a lot along the way, and we want other communities to benefit from our experiences and do their part to prepare for peak oil as well."

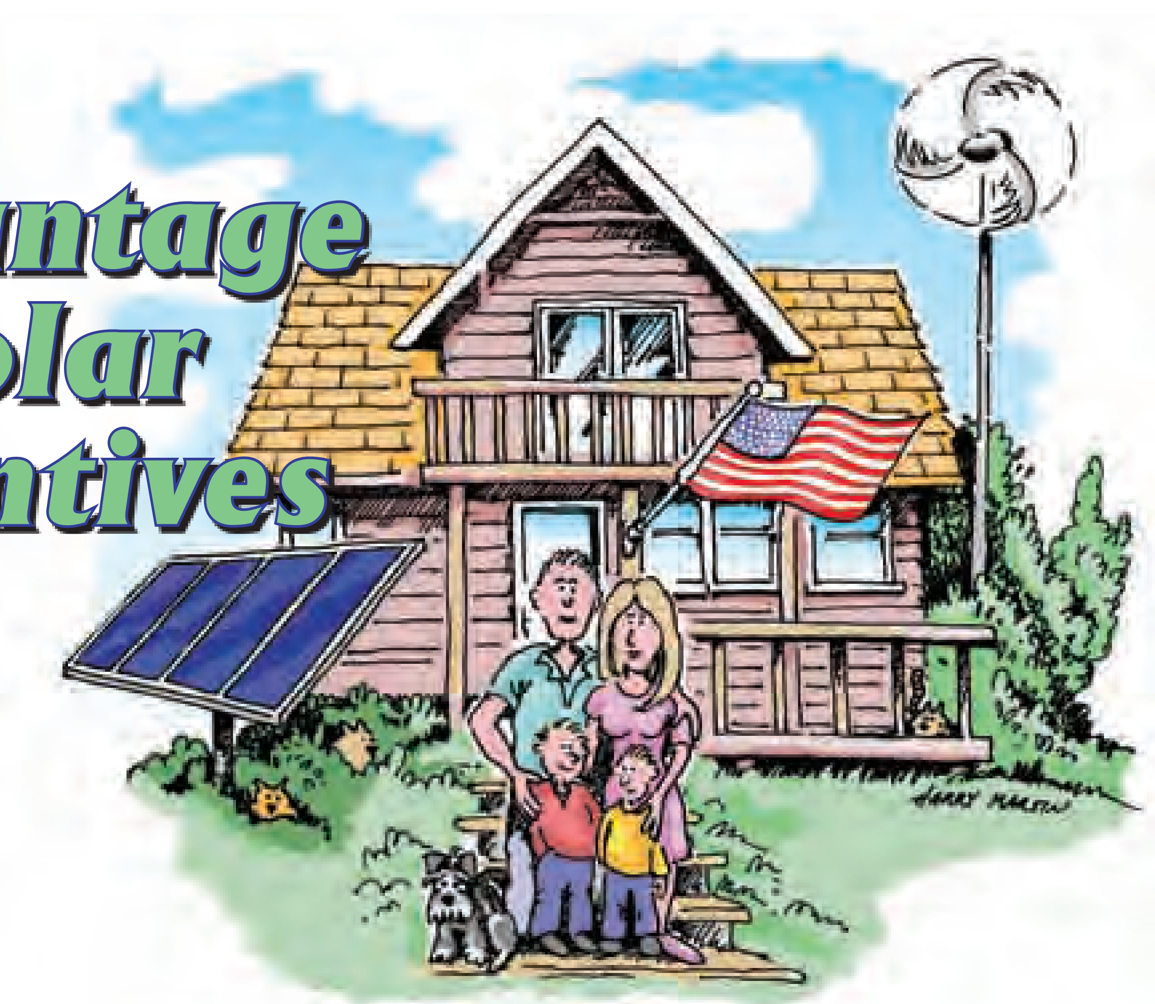
Access

Associate Editor **Kelly Davidson** (kelly.davidson@homepower.com) was disappointed that her old clunker did not qualify for "Cash for Clunkers," but she's happy that the program got some gas-guzzlers off the road. Until next time, she's grateful that her 1999 Toyota Corolla still takes her from point A to point B, and gets 20-plus miles per gallon while doing it.

Plymouth Area RE Initiative • 603-536-5030 • www.plymouthenergy.org

Apricus • www.apricus.com • SHW systems

Take Advantage of Solar Incentives



with Mo Rousso

Federal, state, and utility incentives make investing in solar energy for your home more affordable than ever. Here are some programs that are available and information on how you can put them to work for your pocketbook.

Federal Incentives for Residential Systems

The primary incentive from the federal government is the investment tax credit (ITC), initially brought into law as part of the Energy Policy Act of 2005. The ITC was for PV systems, solar hot water (SHW), and fuel cells, and was calculated as 30% of the qualified expenditure for the system, with a cap of $2,000 for residences. In late 2008, HR1424 extended the ITC to include small wind systems (up to 100 kW). Additional provisions included an eight-year extension of the ITC until December 31, 2016, and the ability to apply the ITC against the alternative minimum tax for federal tax returns. The American Reinvestment and Recovery Act (ARRA) of 2009 removed the $2,000 cap for all PV, SHW, and small wind systems placed into service after 2008.

So what does this mean for you? A tax credit is applied against taxes owed. It is not a deduction, which is merely subtracted from income to determine the amount of tax to be paid. Credits result in much higher tax savings than deductions. According to the feds, their PV and wind system tax credit covers system costs, which besides the cost of components, may include labor for site preparation and system installation, and wiring to connect the system to the home. If the system is for a new home, the "placed in service" date is when the homeowner obtains occupancy. If the federal tax credit exceeds tax liability for that year, the excess may be carried forward (through 2016), until it is depleted.

SHW systems carry additional requirements for tax-credit eligibility. First, the equipment must be certified by the Solar Rating Certification Corporation (SRCC) or a comparable entity qualified by the state in which the system is installed. Second, the system must provide at least 50% of the home's water heating needs. This credit applies only to domestic water heating—solar heating systems for pools and spas aren't eligible.

Regardless of the technology, the home served by the RE system does not have to be the taxpayer's *principal* residence to qualify for the credit.

The tax code provision includes another potential incentive. According to Section 136 of the IRS Code, rebates, buy-downs, and other subsidies provided by public utilities are nontaxable. To quote the IRS: "Gross income shall not include the value of any subsidy provided (directly or indirectly) by a public utility to a customer for the purchase or installation of any energy conservation measure."

The term "energy conservation measure" includes installations or modifications—such as solar- and wind-electric systems, and solar water heating systems—that reduce consumption of utility electricity or natural gas. Eligible dwelling units include houses, apartments, condominiums, mobile homes, and boats.

Given the IRS's definition of "energy conservation measure," a case could be made that utility rebates for residential SHW and PV projects may be nontaxable. Consult with your CPA or a tax attorney if you're considering using this provision for your PV, DHW, or small wind system because it makes the calculation of the ITC a bit more complex. If you and your CPA decide to take advantage of Section 136 and elect not to include the cash subsidy in your income, then you must reduce the basis of the "Qualified Expenditure" on which the Section 25D payment is computed by the full amount of that subsidy. On the other hand, if you obtain a rebate or other cash subsidy and elect to include it in your income, then you do not need to reduce your "Qualified Expenditure" basis for the purposes of determining the ITC. It is simply 30% of the "Qualified Expenditure."

State, Local Government & Utility Incentives

Beyond the feds, state, city, and utility incentives are available depending on where you live. These incentives include:

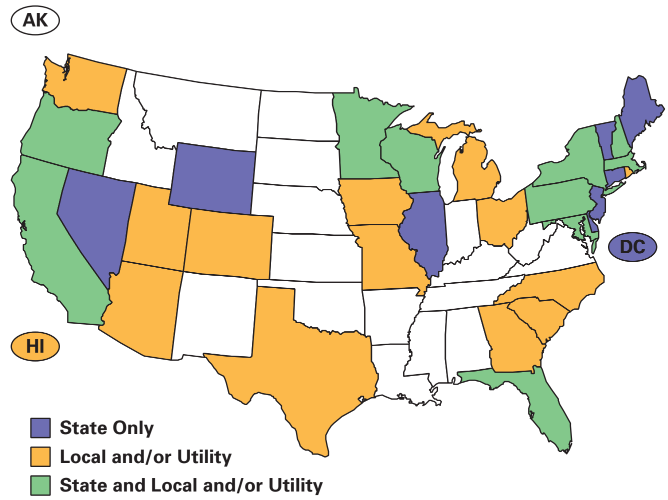
Green Building: Some cities and counties offer permit fee reductions or waivers for solar energy systems, as well as expedited permitting. For instance, the City of Santa Monica, California, not only has waived its building permit fees for solar energy systems, but has established guidelines in an effort to standardize PV installation and inspection procedures.

Leasing or Lease-Purchase: Some municipalities and utilities now offer low-cost leasing of solar equipment. Santa Clara, California's solar water heating program supplies, installs, and maintains systems for residents. Owned by the city, the home or building owner simply pays an initial installation fee, plus a monthly utility fee to lease the system.

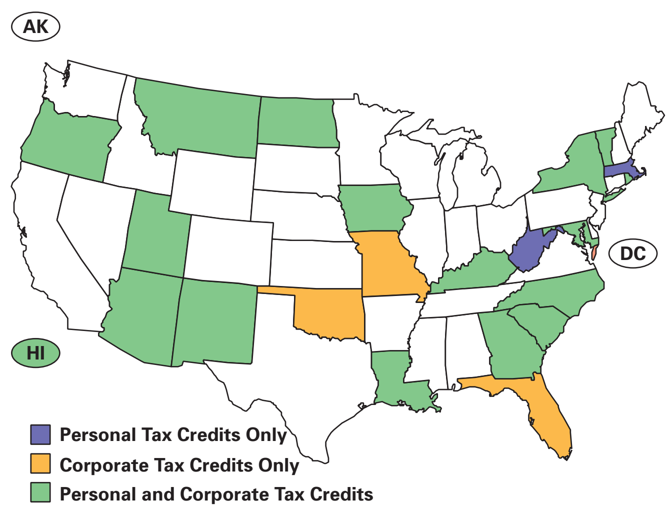
Local Loan Programs: Numerous municipalities have established relationships with finance companies to provide low-cost loans to their residents. In Berkeley, California, for example, the loans are repaid over time through an additional property tax assessment. Typically, homeowners must agree to an energy-efficiency assessment of their home to qualify for the loans.

Local Rebates: Several municipalities provide cash rebates to homeowners who install RE systems. These rebates are typically in addition to any available utility or state rebate. In June 2008, the San Francisco Public Utilities Commission started providing rebates to residents who install PV systems, and additional rebates for low-income residents. The program was made retroactive to cover systems installed on or after December 11, 2007.

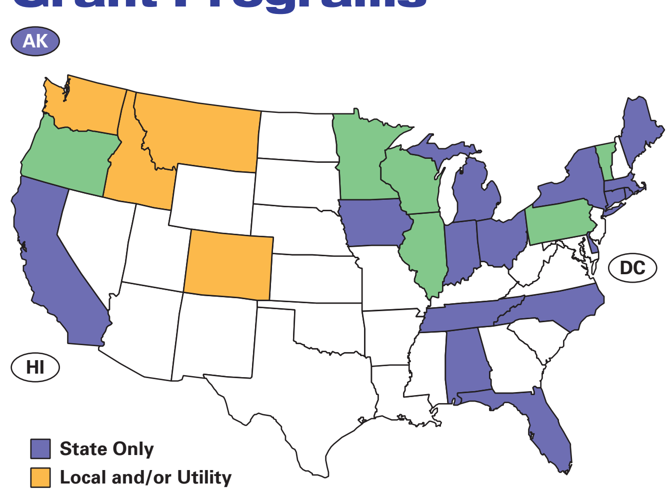
Rebate Programs



Tax Credits for RE



Grant Programs



Map data courtesy www.dsireusa.org

Check Out DSIRE

The Database of State Incentives for Renewables & Efficiency (DSIRE, www.dsireusa.org) is a comprehensive source of information on state, local, utility, and federal incentives and policies that promote renewable energy and energy efficiency. Established in 1995 and funded by the U.S. Department of Energy, DSIRE is an ongoing project of the North Carolina Solar Center and the Interstate Renewable Energy Council.

DSIRE contains lists and links for all of the programs mentioned in this article and many more. It is sorted by federal and states and is as simple as clicking on your state on the map, which brings up a list of all incentives with detailed information.

Production Incentives: Europe is a leader in implementing renewable energy, and forward-thinking policy and attractive incentives have largely been the basis for its success. European countries have been using feed-in-tariffs (FITs, see *Power Politics*, *HP133*), a legislated tariff that requires utilities to pay a premium rate over a predetermined period (15 to 25 years, typically) for all electricity produced by renewable sources and fed into the grid. Typically, FITs can be three to four times that of the retail electricity tariff, meaning that homeowners installing RE systems dramatically reduce their system's payback period.

In the United States, the Gainesville Regional Utilities (GRU), a municipal utility owned by the City of Gainesville, Florida, was one of the first to offer a FIT for PV systems. Similar to the German FIT model which legislates utilities to purchase energy from qualified PV systems via a standard offer contract, GRU will offer a FIT at set rates for a period of 20 years. Under GRU's program, homeowners with PV systems smaller than 10 kW have the option to enter into a FIT agreement and sell 100% of their electricity to GRU, or to net meter and only send the excess electricity to GRU. For qualified residents who choose net metering, GRU also offers a rebate. FIT programs are also currently under development in Vermont and Oregon, according to Rusty Haynes of the North Carolina Solar Center.

If there's a program in your area, how do you determine if a FIT is right for you? Depending on the tariff schedule, energy consumption profile, and size of your PV system, you may elect to evaluate which FIT scheme to adopt in two different ways. First, if you are a relatively low user of electricity and rarely use enough energy to reach peak tiers, you may get more financial benefit by selling all of your power to the utility. Conversely, if you are a heavy user and are space-constrained so that you end up installing a peak-shaving PV system, then you may want to opt for the net-metering option and claim the rebate. Most financial advisors would conduct a net-present-value calculation, where typically, the more cash you get up front (i.e., rebate), the better the economics.

Chelan County Public Utilities District in Washington state also has a variant on a FIT program—Sustainable Natural Alternative Power (SNAP). It has a variable FIT rate, depending on the number of customers who pay into their green pricing program and the overall energy production by participants. This approach serves a double purpose. First, the green pricing program allows ratepayers to elect to pay a slight premium for renewable electricity. Second, the green-pricing premium helps subsidize the FITs for those who want to invest in installing green energy systems. In 2008, the tariff was 25 cents per kWh.

In May 2005, Washington enacted Senate Bill 5101, establishing production incentives for individuals, businesses, and local governments that generate electricity from solar power, wind power, or anaerobic digesters. The incentive amount paid to the producer starts at a base rate of 15 cents per kWh and is adjusted by a multiplier, based on the system type, with larger multipliers for systems using equipment manufactured in Washington state.

These multipliers result in production incentives ranging from 12 cents to 54 cents per kWh, capped at $5,000 per year. Ownership of the renewable-energy credits associated with generation remains with the customer-generator and does not transfer to the state or utility.

Property Tax Exemption: Several states offer property-tax abatements or exemptions. For example, in Oregon, the added value to any property from the installation of a qualifying renewable energy system such as PV, SHW, or wind may not be included in the reassessment of the property's value and is exempt from additional property tax. This exemption is intended for the end users of the property. Many other states have exempted PV, SHW, and small wind from additional property taxes, including California, Texas, Kansas, Massachusetts, Michigan, Tennessee, Indiana, Nevada, and Rhode Island.

Sales Tax Exemption: As with property taxes, a number of states exempt eligible renewable energy systems from sales tax. As an example, Colorado exempts from their sales-and-use tax all components used in the production of AC electricity from a renewable energy source. In addition, effective July 1, 2009, through July 1, 2017, all components used in solar thermal systems are also exempt from sales-and-use tax. The exemption only applies to state taxes, not taxes assessed by incorporated municipalities and counties. However, the state has granted local jurisdictions the authority to adopt the exemption for renewable energy equipment at their option. Other states that have implemented RE sales-tax relief include Vermont, Washington, Massachusetts, Minnesota, Arizona, Wyoming, New Jersey, Maryland, Florida, and Ohio.

State Loan Programs: Numerous states offer low-interest loans for residential renewable energy projects. To illustrate, the Oregon Small-Scale Energy Loan Program finances small-scale, distributed generation projects, like rooftop PV and SHW systems. The state will loan up to $20 million for a single project, although most loans are for less than $100,000. Terms are pegged to the expected life cycle of the technology and are typically five to 15 years in length. Interest rates vary.

Iowa's Alternate Energy Revolving Loan Program provides up to 50% of the cost of a qualifying PV, SHW, or small wind system, and offers attractive terms of 0% interest for up to 20 years.

State Rebate Programs: Many states offer cash rebates for the implementation of residential PV and SHW systems. California is the leader in this and offers several types of rebate programs. In January 2006, the California Public Utilities Commission (CPUC) implemented the California Solar Initiative (CSI) program, which provides more than $3 billion in incentives for solar-energy projects. The program's objective is to have 3,000 megawatts of PV capacity by 2016.

Originally, the CSI program provided incentives only to the customers of the state's investor-owned utilities. However, in August 2006, the CSI was expanded to encompass municipal utility territories and is required to offer nearly $800 million of incentives beginning in 2008. For systems less than 50 kW, incentives are awarded as a one-time, up-front payment based on expected performance, which is calculated using equipment ratings and installation factors such as geographic location, tilt, orientation, and shading. Applicants may choose to receive their incentives via the performance-based incentive (PBI), which is calculated against the actual number of kWh generated. The PBI runs over five years and is paid monthly. All installations larger than 50 kW must take the PBI. Rebates decline per a published schedule once a certain targeted MW of PV capacity is reached.

Although the CSI primarily funds PV projects, the CPUC also authorized $2.6 million for a pilot SHW program (except pool and spa systems). The pilot is managed by the California Center for Sustainable Energy and is limited to customers of San Diego Gas and Electric. The maximum residential rebate is $1,500 and is adjusted downward based on expected performance. Equipment installed must carry the SRCC's OG100 rating.

Utility Loan Programs: Some utilities offer loans that are either funded from within or through an established finance company. In New Jersey, utility company PSE&G offers low-interest loans for PV systems to customers. Residential customers can receive loan terms of 10 years at 6.5% interest. The loan may be coupled with the New Jersey rebate for homeowners and covers 40 to 60% of the system cost. Customers can repay their loans with a combination of cash

Many utilities offer rebates for PV, SHW, and small wind systems. In California alone, there are 27 utilities offering rebates to buy down the system's purchase price. For PV and small wind, the rebate is usually based on the system size, measured in watts. For SHW, the rebate is usually calculated on the number or square footage of the collectors.

Example Incentives

	San Diego, CA		Aspen, CO		Long Island, NY	
	PV (2 kW)	SHW (80 sq. ft.)	PV (2 kW)	SHW (80 sq. ft.)	PV (2 kW)	SHW (80 sq. ft.)
Cost	$15,120	$4,000	$15,000	$4,000	$14,000	$4,000
Federal tax credit	4,536	1,200	4,500	1,200	4,200	1,200
Maximum rebate	3,100	1,500	4,000	1,000	7,000	0
Out-of-pocket cost	$7,484	$1,300	$6,500	$1,800	$2,800	$2,800
Percent of cost	49.5%	32.5%	43.3%	45.0%	20.0%	70.0%
Building permit	No charge		Fee		Fee	
Sales tax	Not exempt		Exempt		Exempt	
Property tax	Exempt		Depends on county		Exempt, 15 yrs.	

Federal tax credits are calculated assuming all rebate funds are claimed as part of the household taxable income.

and solar renewable energy certificates, with 1 SREC equal to 1 megawatt-hour of green electricity. Since the state trades SRECs, the value of the SREC may vary. If it goes higher, then customers will enjoy the extra benefits.

Utility Rebates: Many utilities offer rebates for PV, SHW, and small wind systems. In California alone, there are 27 utilities offering rebates to buy down the system's purchase price. For PV and small wind systems, the rebate is usually based on the system size, measured in watts. For SHW, the rebate is usually calculated on the number or the square footage of the collectors.

As an example, California's Earth Advantage Rebate Program offers rebates for PV and SHW systems to residential and business customers of Redding Electric Utility. Rebates for PV vary from $2.60 to $3.55 per watt, depending on tilt, azimuth, and whether there is a tracker involved. SHW is 50% of project cost—up to $1,000 for the first collector, $500 for the second, and $250 for the third.

Seize the Solar Opportunity

All homeowners are eligible for the federal incentives—if they have a tax liability. Additional incentives vary from state to state, city to city, or utility to utility within the same state. To capture all the available incentives, do your homework. A reputable solar or wind installer should be able to help you reap all the incentives you are eligible for.

We are seeing more and more great incentives, allowing homeowners to get excellent returns on their PV or SHW investment. The recession has created a buyer's market, and eager contractors and equipment suppliers are selling their products and services at better-than-ever prices. Low prices, the current administration's desire to promote renewable energy, and the fact that many states are creating market demands by reducing out-of-pocket costs make this a very good time to install renewable energy systems.

Access

Mo Rousso (mrousso@heliomu.com) engineered and installed his first solar energy project in 1975. In 2001, he founded HelioPower, a leading solar power integration firm based in California. Mo is currently CEO of Helio mU, a PV finance company. He holds an MBA with an emphasis in finance, and a bachelor's degree in mechanical engineering.

Portions of this article are based on or adapted from the The Database of State Incentives for Renewables & Efficiency (DSIRE, www.dsireusa.org) and are used with the permission of North Carolina State University and DSIRE.

2010 PV Module Guide

by Justine Sanchez

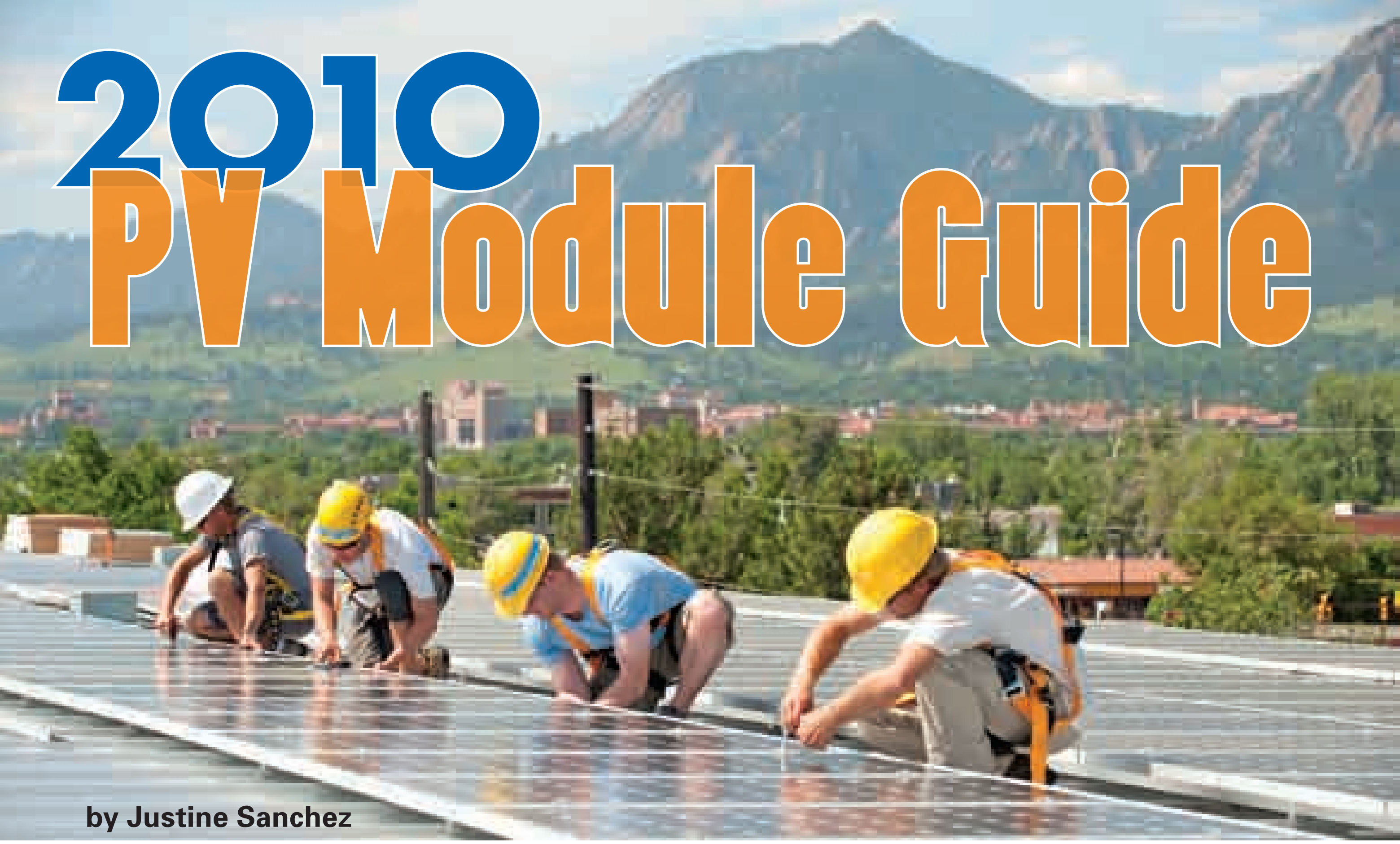


Photo www.topherdonahue.com

These are exciting times for the PV module market—due to political and economic forces at work, the PV industry is on the move and changing at a rapid clip, and new products are being added regularly.

Our previous buyer's guides have focused on module specifications, and have given detailed information on how to apply the data to the design process. This guide focuses on the criteria used to select the modules included in the table, along with residential PV price trends, specifications definitions, and general advice to PV module shoppers.

PV Module Criteria

Only crystalline modules 100 watts or larger and 60 watts and larger for thin-film are included in this guide. They also meet the following criteria:

- Listed on the California Energy Commission's (CEC) SB1 guidelines-compliant module list, as of October 1, 2009
- Manufacturers must have U.S.-based sales offices
- Available to the residential and small commercial market; in stock and ready to ship

CEC SB1 guidelines-compliant module list—As of July 1, 2009, the CEC provides incentives only for modules that have been independently tested and are listed on the SB1 guidelines-compliant module list hosted by the Go Solar California Web site (see Access). Prior lists of modules eligible for incentives in California only had to be in compliance with Underwriters Laboratories (UL) 1703—a safety standard that doesn't reflect module performance.

Under the CEC guidelines, incentive-eligible modules must report the following performance parameters, as verified by an independent testing agency:

- Maximum power
- Temperature coefficients
- Nominal operating cell temperature (NOCT)
- Performance at STC and NOCT
- Performance at low irradiance (200 W/m^2).

PTC Ratings

Based on a higher cell temperature (about 25 to 30°C higher) than STC (standard test conditions), PTC (PVUSA test conditions) testing provides a more realistic module output value than STC. The higher cell temperature (which is based on NOCT) is used with the maximum power temperature coefficient to calculate the PTC rating.

Before July 1, 2009, NOCT and maximum power temperature coefficients were simply unverified values supplied by PV module manufacturers. Now, independent testing agencies verify these values—a big improvement to the PV industry and better yardstick for predicting actual performance. Another testament to the need for third-party verification? About 65% of the initial 475 modules relisted on the CEC-eligible module list were found to have up to 6.3% overrated PTC ratings prior to testing under the new requirement.

The test laboratory must be affiliated with the International Laboratory Accreditation Cooperation (ILAC), which includes CSA, Intertek (ETL), TUV Rhineland of North America, and UL, but also includes other testing facilities around the world. Once these parameters are tested and reported, module PTC ratings (see "PTC Ratings" sidebar) can be calculated and used to determine California's incentive amount.

Independent testing has been required in Europe for many years, but before July 2009, no U.S. incentive programs required this testing. As a result, the likelihood of underperforming PV modules entering the U.S. was high. Now that the CEC requires testing for its PV incentive programs, it is expected that other programs in the United States will follow suit.

Modules that have been independently verified are thought to carry a vote of confidence from their manufacturer, since they've spent the extra time and money for the verification process. More PV modules are added to this list regularly. For an up-to-date list, visit the Go Solar California Web site.

U.S.-based sales offices. An increasing number of international companies are supplying the U.S. PV market, and some of their modules appear on the CEC list. However, not all of these companies have offices located stateside. End users and installers should have ready access to customer support, so we have included only those PV manufacturers that have offices in the United States.

Product in stock and available to the residential PV market. To be included in the guide, module suppliers have stated that they will have these products in stock and ready to ship by the magazine's issue date (December 2009).

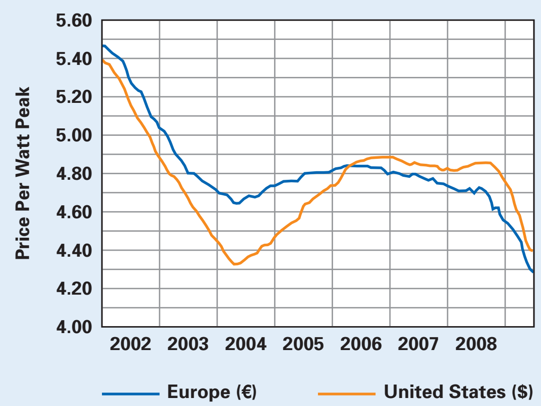
And, since *Home Power* is focused on home-scale subjects, our final criterion is that modules are available to the residential and small-commercial market.

Dropping Module Prices

PV market growth and module-supply limitations of previous years sparked a huge module production ramp up in 2008. However, this increase in module supply then collided with the economic downturn—which means less money available and lower PV sales. The result was lower price per watt as manufacturers try to unload surplus stock.

Module prices are not listed in the table, since that price varies depending on distributor and quantity. However, we have included information from Solarbuzz's online retail price per watt survey, which shows the average retail module price dropping from $5.40 per watt in 2001 to the current average retail price of $4.40 (September 2009). While this graph shows the *average* retail values from the survey, a quick Internet search revealed that modules can be easily found for lower prices. (The lowest price we found was about $3 per watt for unblemished, listed modules.) This price drop, along with local, state, and federal incentive programs for PV systems, means that it's an excellent time to buy. (For more information, see the solar incentives article in this issue.) Also remember that price is only one criterion of concern to module shoppers—also consider warranty terms, customer service, and company longevity and reputation.

PV Module Retail Price Index



Data courtesy www.solarbuzz.com

The Specs

All module specifications in the table were provided by the manufacturers.

Cell type

The type of silicon cell, based on the cell manufacturing process. Amorphous silicon (a-Si) arrays require nearly twice as much area to produce an equal amount of power as crystalline modules. On the flip side, amorphous modules can offer better high-temperature performance (see the "Maximum Power Temperature Coefficient" specification).

Rated power at STC (W)

The module power rating at standard test conditions (STC)—1,000 watts per square meter solar irradiance, 25°C (77°F) *cell* temperature. Because module output is dependent on environmental conditions, modules are tested at STC so they can be compared and rated on a level playing field. Actual power output in the field will vary as available sunlight and module temperature fluctuate.

Rated power at PTC (W)

The module power rating at PVUSA test conditions (PTC)—1,000 watts per square meter solar irradiance, 20°C (68°F) *ambient* temperature, and wind speed of 1 meter per second at 10 meters above ground level. This rating translates into a much higher—and more realistic—*module* operating temperature and is used in some incentive programs to calculate incentive amounts (see "PTC Ratings" sidebar).

(continued on page 60)

Manufacturer	Model	Cell Type	Power @ STC (W)	Power @ PTC (W)	Power Tolerance (%)	Power Per Sq. Ft. (W)	Module Efficiency (%)	Max. Power Voltage (Vmp)	Max. Power Current (Imp)
Aleo Solar www.aleo-solar.com	S_16 165	Poly	165	146.1	+/-3	11.1	12.0	23.2	7.11
	S_16 170		170	150.6		11.5	12.3	23.4	7.26
	S_16 175		175	155.2		11.8	12.7	23.6	7.41
	S_16 180		180	159.7		12.1	13.1	23.8	7.55
	S_16 185		185	164.3		12.5	13.4	24.0	7.70
	S-18 210		210	186.2		11.9	12.8	28.4	7.41
	S_18 215		215	190.8		12.2	13.1	28.6	7.53
	S_18 220		220	195.3		12.4	13.4	28.7	7.65
	S_18 225		225	199.9		12.7	13.7	28.9	7.78
	S_18 230		230	204.5		13.0	14.0	29.1	7.90
BP Solar www.bpsolar.us	BP 4175T	Mono	175	157.2	+5/-3	13.0	14.0	35.4	4.94
	BP 175B	Poly	175	157.3	+/-5	12.9	13.9	35.8	4.90
	BP 175I		175	157.3		12.4	13.3	35.8	4.90
	BP 4180T	Mono	180	161.8	+5/-3	13.3	14.4	35.8	5.03
	BP 3180T	Poly	180	161.8		13.3	14.4	35.6	5.00
	BP3220T		220	193.1		12.3	13.2	28.9	7.60
	BP3220B		220	193.1		12.3	13.2	28.9	7.60
	BP3225T		225	197.7		12.5	13.5	29.1	7.70
	BP3230T		230	202.2		12.8	13.8	29.1	7.90
Canadian Solar www.csisolar.com	CS6A-150PE	Poly	150	132.6	+/-3.3	10.7	DNR (Did Not Report)	23.1	6.50
	CS5A-160M	Mono	160	145.4	+/-3.1	11.6		34.9	4.58
	CS6A-160P	Poly	160	139.6		11.4		23.1	6.92
	CS6A-160PE		160	141.7		11.4		23.1	6.92
	CS5A-170M	Mono	170	154.7	+/-2.9	12.4		35.5	4.79
	CS6A-170P	Poly	170	148.6		12.1		23.2	7.33
	CS6P-170PE		170	150.0		9.8		28.7	5.93
	CS5A-180M	Mono	180	164.0	+/-2.8	13.1		36.1	4.99
	CS6A-180P	Poly	180	157.6		12.9		23.6	7.62
	CS6P-180PE		180	159.0		10.4		28.7	6.26
	CS6P-190PE		190	168.1	+/-2.6	11.0		28.8	6.60
	CS6P-200P		200	172.8	+/-2.5	11.6		28.9	6.93
	CS6P-200PE		200	177.1		11.6		28.9	6.93
	CS6P-210P		210	181.7	+/-2.4	12.1		28.9	7.26
	CS5P-220M	Mono	220	201.5	+/-2.3	12.0		46.9	4.69
	CS6P-220P	Poly	220	190.7		12.7		29.3	7.52
	CS5P-230M	Mono	230	210.9	+/-2.2	12.6		47.5	4.84
	CS6P-230P	Poly	230	199.6		13.3		29.8	7.71
	CS5P-240M	Mono	240	220.4	+/-2.1	13.1		48.1	4.99
Day4 Energy www.day4energy.com	Day4 48MC 160	Poly	160	143.3	+/-3.5	11.5	12.4	22.6	7.08
	Day4 48MC 165		165	147.9		11.8	12.7	23.0	7.19
	Day4 48MC 170		170	152.5		12.2	13.1	23.0	7.38
	Day4 48MC 175		175	157.1		12.6	13.5	23.4	7.48
	Day4 48MC 180		180	161.7		12.9	13.9	23.7	7.60
	Day4 48MC 185		185	166.3		13.3	14.3	23.8	7.77
	Day4 48MC 190		190	170.9		13.6	14.7	24.0	7.92
ET Solar www.etsolar.com	ET-M572165	Mono	165	146.5	+3/-1	12.0	12.9	35.8	4.60
	ET-M572170		170	151.1		12.4	13.3	36.1	4.71
	ET-M572175		175	155.7		12.7	13.7	36.2	4.83
	ET-M572180		180	157.7	+/-3	13.1	14.1	36.3	4.95
	ET-M572185		185	162.2		13.5	14.5	36.3	5.09
	ET-P654190	Poly	190	167.9	+3/-1	12.0	12.9	26.8	7.10
	ET-P654195		195	172.4		12.3	13.3	27.0	7.22
	ET-P654200		200	176.9		12.6	13.6	27.2	7.36
	ET-P654205		205	181.5		13.0	13.9	27.3	7.50
	ET-P654210		210	186.1	+/-3	13.3	14.3	27.5	7.63
	ET-P672255		255	226.6	+3/-1	12.2	12.1	35.2	7.23
	ET-P672260		260	231.2		12.4	13.4	36.0	7.23
	ET-P672265		265	235.8		12.7	13.7	36.4	7.28
	ET-P672270		270	237.2		12.9	13.9	36.4	7.42
	ET-P672275		275	241.7		13.2	14.2	36.7	7.49
	ET-P672280		280	246.3	+/-3	13.4	14.4	36.7	7.63

Open-Circuit Voltage (Voc)	Short-Circuit Current (Isc)	Pmp Temp. Coeff. (%/°C)	Voc Temp. Coeff. (%/°C)	Isc Temp. Coeff. (%/°C)	Nominal Operating Cell Temp. (°C)	Series Fuse Rating (A)	Connector Type	Frame Color	Back-Sheet Color	Length (In.)	Width (In.)	Depth (In.)	Weight (Lbs.)	Materials Warranty (Yrs.)	Power Warranty (Yrs.) 90%/80%
29.6	7.69	-0.48	-0.34	0.04	48	15	Tyco	Silver	White	65.35	32.68	1.97	37.50	10	10/25
29.8	7.82														
30.0	7.95														
30.2	8.07														
30.4	8.20														
35.9	8.03	-0.46									38.98		46.30		
36.1	8.13														
36.3	8.24														
36.4	8.34														
36.6	8.44														

Open-Circuit Voltage (Voc)	Short-Circuit Current (Isc)	Pmp Temp. Coeff. (%/°C)	Voc Temp. Coeff. (%/°C)	Isc Temp. Coeff. (%/°C)	Nominal Operating Cell Temp. (°C)	Series Fuse Rating (A)	Connector Type	Frame Color	Back-Sheet Color	Length (In.)	Width (In.)	Depth (In.)	Weight (Lbs.)	Materials Warranty (Yrs.)	Power Warranty (Yrs.) 90%/80%
43.6	5.45	-0.50	-0.36	0.07	47	20	MC4	Silver	White	62.48	31.10	1.97	33.95	5	12/25
43.6	5.47					15	MC3	Black	Grey	62.72	31.10				
43.6	5.47								Grey	62.48	32.61				
43.6	5.58					20	MC4	Silver	White	62.48	31.10				
43.6	5.40									62.48	31.10				
36.6	8.20									65.63	39.37		42.77		
36.6	8.20							Black	Grey						
36.6	8.30							Silver	White						
36.7	8.40														

Open-Circuit Voltage (Voc)	Short-Circuit Current (Isc)	Pmp Temp. Coeff. (%/°C)	Voc Temp. Coeff. (%/°C)	Isc Temp. Coeff. (%/°C)	Nominal Operating Cell Temp. (°C)	Series Fuse Rating (A)	Connector Type	Frame Color	Back-Sheet Color	Length (In.)	Width (In.)	Depth (In.)	Weight (Lbs.)	Materials Warranty (Yrs.)	Power Warranty (Yrs.) 90%/80%
28.8	7.12	-0.42	-0.35	0.08	45	15	MC4	Silver	White	52.13	38.66	1.57	35.27	6	10/25
43.6	4.97	-0.45		0.06		10				62.80	31.54		34.17		
28.9	7.51					15				52.13	38.66		35.27		
28.9	7.51	-0.42		0.08						52.13	38.66		35.27		
44.1	5.19	-0.45		0.06		10				62.80	31.54		34.17		
29.2	7.85					15				52.13	38.66		35.27		
35.8	6.62	-0.42		0.08						64.49	38.66		44.09		
44.5	5.40	-0.45		0.06		10				62.80	31.54		34.17		
29.4	8.20					15				52.13	38.66		35.27		
35.9	6.98	-0.42		0.08						64.49	38.66		44.09		
36.0	7.33														
36.2	7.68	-0.45		0.06											
36.2	7.68	-0.42		0.08											
36.4	7.91	-0.45		0.06											
58.4	5.10					10				63.07	41.77				
36.6	8.09					15				64.49	38.66				
58.8	5.25					10				63.07	41.77				
36.8	8.34					15				64.49	38.66				
59.3	5.40					10				63.07	41.77				

Open-Circuit Voltage (Voc)	Short-Circuit Current (Isc)	Pmp Temp. Coeff. (%/°C)	Voc Temp. Coeff. (%/°C)	Isc Temp. Coeff. (%/°C)	Nominal Operating Cell Temp. (°C)	Series Fuse Rating (A)	Connector Type	Frame Color	Back-Sheet Color	Length (In.)	Width (In.)	Depth (In.)	Weight (Lbs.)	Materials Warranty (Yrs.)	Power Warranty (Yrs.) 90%/80%
28.3	7.70	-0.44	-0.33	0.03	47	15	Tyco	Silver	White	51.46	39.01	1.38	38.28	5	10/25
28.6	7.80														
28.8	7.90														
29.2	8.05														
29.4	8.10														
29.5	8.20														
29.7	8.30														

Open-Circuit Voltage (Voc)	Short-Circuit Current (Isc)	Pmp Temp. Coeff. (%/°C)	Voc Temp. Coeff. (%/°C)	Isc Temp. Coeff. (%/°C)	Nominal Operating Cell Temp. (°C)	Series Fuse Rating (A)	Connector Type	Frame Color	Back-Sheet Color	Length (In.)	Width (In.)	Depth (In.)	Weight (Lbs.)	Materials Warranty (Yrs.)	Power Warranty (Yrs.) 90%/80%
44.1	5.19	-0.47	-0.40	0.06	44	10	MC4	Silver	White	62.20	31.81	1.97	34.20	5	12/25
44.2	5.30														
44.3	5.50														
44.6	5.61														
44.6	5.80														
32.5	7.72	-0.46	-0.35	0.07	45	12				58.35	39.06		39.30		
32.8	7.98														
32.7	7.86														
32.8	8.10														
32.8	8.30														
43.9	7.85									77.00	39.10	2.00	50.70		
43.5	7.79														
43.6	7.90														
43.6	7.90														
43.8	7.96														
43.8	7.98														

Manufacturer	Model	Cell Type	Power @ STC (W)	Power @ PTC (W)	Power Tolerance (%)	Power Per Sq. Ft. (W)	Module Efficiency (%)	Max. Power Voltage (Vmp)	Max. Power Current (Imp)
Evergreen Solar www.evergreensolar.com	ES-C-110-fa2	Ribbon	110	99.1	+5/-5	9.9	10.6	16.8	6.57
	ES-C-115-fa4		115	103.7		10.3	11.1	17.9	6.42
	ES-C-120-fa2		120	108.3		10.8	11.6	17.3	6.95
	ES-C-125-fa4		125	112.9		11.2	12.1	18.4	6.81
	ES-B-180-fa1/fb1		180	154.6	+3.4/-2	11.2	12.0	17.1	10.53
	ES-B-190-fa1/fb1		190	163.4	+2.6/-2	11.8	12.7	17.4	10.92
	ES-B-195-fa1/fb1		195	167.9	+2.6/-0	12.1	13.1	17.6	11.08
	ES-A-200-fa3		200	180.7	+2.5/-0	11.8	12.7	18.1	11.05
	ES-A-205-fa3		205	185.4	+2.4/-0	12.1	13.1	18.2	11.27
	ES-A-210-fa3		210	190.0		12.4	13.4	18.3	11.48
GE Energy www.gepower.com	GEPVp-200-M	Poly	200	173.1	+/-5	12.8	13.9	26.3	7.60
	GEPVp-205-M		205	177.6		13.1	14.2	27.2	7.60
Kaneka www.pv.kaneka.co.jp	G-SA060	a-Si	60	57	+10/-5	5.9	6.3	67	0.9
Kyocera www.kyocerasolar.com	KD130GX-LP	Poly	130	114.8	+/-3.8	12.0	12.9	17.7	7.39
	KD135GX-LP		135	119.4	+/-3.7	12.5	13.4	17.7	7.63
	KD135GX-LPU		135	119.4		14.0	13.4	17.7	7.63
	KD185GX-LPU		185	162.5	+/-2.7	11.6	13.9	23.6	7.84
	KD205GX-LPU		205	180.0	+2.4/-0	12.8	13.8	26.6	7.71
	KD210GX-LPU		210	184.6	+2.3/-0	13.1	14.1	26.6	7.90
	KD215GX-LPU		215	189.1		13.4	14.4	26.6	8.09
Lumos www.lumossolar.com	LS 185	Mono	185	165.6	+/- 3	13.5	14.5	37.1	5.01
Mitsubishi www.mitsubishielectricsolar.com	PV-EE120MF5N	Poly	120	108.7	+10/-5	11.1	11.9	17.2	6.99
	PV-EE125MF5N		125	112.4		11.5	12.4	17.3	7.23
	PV-EE130MF5N		130	117.0		12.0	12.9	17.4	7.47
	PV-UD175MF5		175	157.0	+/-3	11.8	12.7	23.9	7.32
	PV-UD180MF5		180	161.6		12.1	13.0	24.2	7.45
	PV-UD185MF5		185	166.2		12.4	13.4	24.4	7.58
	PV-UD190MF5		190	169.8		12.8	13.7	24.7	7.71
NingBo Solar www.nbsolar.com	TDB125×125-72-P 150W	Mono	150	133.2	+/-5	10.9	11.8	35.2	4.26
	TDB125×125-72-P 155W		155	137.7		11.3	12.2	35.4	4.38
	TDB125×125-72-P 160W		160	142.3		11.7	12.5	35.6	4.50
	TDB125×125-72-P 165W		165	146.8		12.0	12.9	35.8	4.61
	TDB125×125-72-P 170W		170	151.4		12.4	13.3	36.0	4.72
	TDB125×125-72-P 175W		175	155.9		12.7	13.7	36.2	4.84
	TDB125×125-72-P 180W		180	160.5		13.1	14.1	36.4	4.95
Pevafersa www.pevafersa-america.com	IP-VA 180	Mono	180	159.2	+3/-2	13.03	14.1	35.3	4.83
	IP-VAP210	Poly	210	183.7		12.02	13.0	27.47	7.58
	IP-VAP230		230	201.0		13.17	14.2	27.66	7.72
REC www.recgroup.com	REC205AE-US	Poly	205	178.2	+/-3	11.5	12.4	27.2	7.60
	REC210AE-US		210	182.7		11.8	12.7	27.6	7.60
	REC215AE-US		215	187.2		12.1	13.0	28.0	7.70
	REC220AE-US		220	191.7		12.4	13.3	28.4	7.80
	REC225AE-US		225	196.2		12.7	13.6	28.8	7.80
	REC230AE-US		230	200.7		12.9	13.9	29.1	7.90
Sanyo www.sanyo.com/solar	HIT-190BA19	Mono, a-Si	190	171.2	+10/-0	15.2	16.4	54.8	3.47
	HIT-186DA3[1]		186	172.6		14.2[2]/18.2[3]	15.3[2]/19.6[3]	54.8[2]/55.1[3]	3.40[2]/4.32[3]
	HIT-190DA3[1]		190	176.8		14.6[2]/18.6[3]	15.7[2]/20.0[3]	55.3[2]/55.6[3]	3.44[2]/4.37[3]
	HIT-195DA3[1]		195	181.1		14.9[2]/19.1[3]	16.1[2]/20.5[3]	55.8[2]/56.1[3]	3.50[2]/4.45[3]
	HIT-195BA19		195	179.8		15.6	16.8	55.3	3.53
	HIT-200BA19		200	184.5		16.0	17.2	55.8	3.59
	HIT-205BA19		205	185.1		16.4	17.7	56.7	3.62
	HIT-205NKHA1		205	190.2		15.1	16.3	40.7	5.05
	HIT-210NKHA1		210	194.9		15.5	16.7	41.3	5.09
	HIT-215NKHA1		215	199.6		15.9	17.1	42.0	5.13

[1] Bifacial module [2] At STC [3] At up to 30% backside irradiance contribution

Open-Circuit Voltage (Voc)	Short-Circuit Current (Isc)	Pmp Temp. Coeff. (%/°C)	Voc Temp. Coeff. (%/°C)	Isc Temp. Coeff. (%/°C)	Nominal Operating Cell Temp. (°C)	Series Fuse Rating (A)	Connector Type	Frame Color	Back-Sheet Color	Length (In.)	Width (In.)	Depth (In.)	Weight (Lbs.)	Materials Warranty (Yrs.)	Power Warranty (Yrs.) 90%/80%
20.9	7.33	-0.43	-0.31	0.05	45	15	J-Box	Silver	White	62.40	25.67	1.60	27.00	5	10/25
22.3	7.15														
21.3	7.62														
22.6	7.37														
21.3	11.64	-0.49	-0.34	0.06	46	20	MC4			61.80	37.50		40.10		
21.5	11.95														
21.7	12.11														
22.6	11.80	-0.43	-0.31	0.05	45			Black		65.00		1.80	41.00		
22.7	11.93														
22.8	12.11														
32.9	8.10	-0.50	-0.36	0.07	50	15	Tyco	Silver	White	58.50	38.60	1.40	39.00	5	10/20
33.0	8.20														
91.8	1.19	-0.26	-0.31	DNR	45	7	MC	Black	N/A	37.79	38.97	1.57	30.2	5	25
22.1	8.06	-0.48	-0.36	0.05	47	15	MC4	Black	White	59.10	26.30	1.40	28.70	5	10/20
22.1	8.37														
22.1	8.37									52.80		1.81			
29.5	8.58	-0.49			48					59.10	39.00		36.30		
33.2	8.36												40.80		
33.2	8.58														
33.2	8.78														
45.4	5.27	-0.47	-0.38	0.10	45	10	MC4	Black / Silver	White	62.20	31.80	1.40	34.10	5	10/25
21.6	7.75	-0.45	-0.34	0.05	48	15	MC4	Black	White	58.90	26.50	1.81	29.80	5	10/25
21.8	7.90														
21.9	8.05														
30.2	7.93									65.30	32.80		37.00		
30.4	8.03														
30.6	8.13														
30.8	8.23														
43.4	4.92	-0.40	-0.35	0.03	47	10	MC4	Silver	White	62.20	31.80	1.80	35.27	5	10/25
43.6	4.98														
43.8	5.04														
44.0	5.10														
44.2	5.16														
44.4	5.22														
44.6	5.28														
44.9	5.19	-0.50	-0.37	0.106	47	10	Tyco	Silver, others avail.	White, others avail.	62.72	31.61	1.81	41.14	5	12/25
36.9	8.10			0.135	48					64.60	38.94	1.91	51.70		
36.8	8.32		-0.36	0.125	49										
36.0	8.30	-0.50	-0.37	0.11	49	15	MC4	Silver / Black	White	65.55	39.02	1.69	48.50	5	10/25
36.1															
36.3															
36.4	8.40														
36.6															
36.8															
67.5	3.75	-0.30	-0.25	0.02	45	15	MC4	Black	White	51.90	34.60	1.80	33.07	5	10/20
67.5[2]/68.2[3]	3.68[2]/4.78[3]				47		MC3	Silver	None	53.20	35.35	2.36	50.70	2	
68.1[2]/68.8[3]	3.70[2]/4.81[3]														
68.7[2]/69.5[3]	3.73[2]/4.85[3]	-0.29													
68.1	3.79	-0.30			45		MC4	Black	White	51.90	34.60	1.80	33.07	5	
68.7	3.83	-0.29													
68.8	3.84														
50.3	5.54	-0.34	-0.28	0.04	46					62.20	31.40		35.30		
50.9	5.57														
51.6	5.61		-0.27	0.03											

Manufacturer	Model	Cell Type	Power @ STC (W)	Power @ PTC (W)	Power Tolerance (%)	Power Per Sq. Ft. (W)	Module Efficiency (%)	Max. Power Voltage (Vmp)	Max. Power Current (Imp)
Schott Solar www.us.schottsolar.com	SAPC-170	Mono	170	149.1	+10/-5	12.1	13.1	34.8	4.90
	SAPC-175		175	151.8		12.5	13.5	35.4	4.95
	POLY 202	Poly	202	177.6	+/-4	11.2	12.1	28.9	6.99
	POLY 210		210	184.8		11.7	12.6	29.3	7.16
	POLY 217		217	191.2		12.0	13.0	29.6	7.33
	POLY 220		220	193.9		12.2	13.1	29.7	7.41
	POLY 225		225	198.4		12.5	13.4	29.8	7.55
	ASE 250	Ribbon	250	221.6	+/-2	9.6	10.3	48.5	5.15
	ASE 260		260	230.6		10.0	10.7	48.7	5.50
	ASE 270		270	239.7		10.3	11.1	49.1	5.50
	ASE 280		280	248.8		10.7	11.5	49.6	5.65
	ASE 290		290	257.9		11.1	11.9	50.1	5.80
	ASE 300		300	267.0		11.5	12.4	50.6	5.90
	ASE 310		310	276.2		11.9	12.8	51.1	6.10
Schüco www.schuco-usa.com	165 SPU-4	Poly	165	146.4	+/-5	11.1	11.9	23.4	7.06
	170 SPU-4		170	150.9		11.4	12.3	23.7	7.19
	175 SPU-4		175	157.0		11.8	12.7	23.9	7.32
	180 SPU-4		180	161.6		12.1	13.0	24.2	7.45
	200 SMAU-1	Mono	200	178.1	+/-3	12.7	14.2	25.4	7.89
	210 SMAU-1		210	187.3		13.3	14.9	26.3	7.98
SET-Solar www.set-solar.com	SDM-170/(165)-72M	Mono	165	145.3	+/-3	12.0	DNR	35.6	4.65
	SDM-170/(170)-72M		170	149.8		12.4		35.8	4.76
	SDM-170/(175)-72M		175	154.3		12.7		36.2	4.85
	SDM-170/(180)-72M		180	158.9		13.1		36.8	4.90
	SDM-170/(185)-72M		185	163.4		13.5		37.5	4.95
Sharp www.solar.sharpusa.com	ND-72ERUC[4]	Poly	72	63.2	+10/-5	5.8	12.5	10.0	7.18
	ND-72ELUC[4]		72	63.2		5.8	12.4	10.0	7.18
	ND-123UJF		123	108.2		11.5	12.4	17.2	7.15
	ND-130UJF		130	113.8		12.2	13.1	17.4	7.50
	ND-N2ECUF		142	124.1		11.4	12.3	19.9	7.13
	ND-N2ECUC		142	124.1		11.4	12.3	19.9	7.13
	NE-165U1		165	144.6		11.8	12.7	34.6	4.77
	NE-165UC1		165	144.6		11.8	12.7	34.6	4.77
	ND-167UC1		167	147.3		11.8	12.7	23.0	7.27
	NE-170U1		170	149.1		12.1	13.1	34.8	4.90
	NE-170UC1		170	149.1		12.1	13.1	34.8	4.90
	NT-170UC1	Mono	170	147.3		12.1	13.1	34.8	4.90
	NT-175U1		175	151.8		12.5	13.5	35.4	4.95
	NT-175UC1		175	151.8		12.5	13.5	35.4	4.95
	ND-176U1Y	Poly	176	152.4		12.4	13.3	23.4	7.52
	ND-176UC1		176	152.4		12.4	13.3	23.4	7.52
	NT-180U1	Mono	180	156.3		12.9	13.8	35.9	5.02
	ND-187UC1	Poly	187	164.7		13.2	14.2	25.8	7.25
	ND-198U1F		198	170.5		12.4	13.4	26.3	7.52
	ND-198UC1		198	170.5		12.4	13.4	26.3	7.52
	ND-200U1F		200	173.0		11.4	12.3	28.4	7.04
	ND-200UC1		200	173.0		11.4	12.3	28.4	7.04
	ND-208U1F		208	180.1		11.9	12.8	28.7	7.25
	ND-208UC1		208	180.1		11.9	12.8	28.7	7.25
	ND-216U1F		216	185.0		12.3	13.3	28.9	7.48
	ND-216UC1		216	185.0		12.3	13.3	28.9	7.48
	ND-U216C1		216	185.0		12.3	13.3	30.2	7.16
	ND-216U2		216	187.3		12.3	13.3	28.7	7.53
	ND-220U1F		220	188.5		12.5	13.5	29.2	7.54
	ND-220UC1		220	188.5		12.5	13.5	29.2	7.54
	ND-224U1F		224	192.6		12.8	13.7	29.3	7.66
	ND-224UC1		224	192.6		12.8	13.7	29.3	7.66
	ND-U224C1		224	192.6		12.8	13.7	30.2	7.42
	ND-V230A1		230	198.0		13.1	14.1	30.3	7.60
	ND-U230C1		230	198.0		13.1	14.1	30.3	7.60
	NU-U230F3	Mono	230	207.1		13.1	14.1	30.0	7.67
	NU-U235F1		235	211.7		13.4	14.4	30.0	7.84

[4] Triangular module, generally installed in pairs making > 100 W

Open-Circuit Voltage (Voc)	Short-Circuit Current (Isc)	Pmp Temp. Coeff. (%/°C)	Voc Temp. Coeff. (%/°C)	Isc Temp. Coeff. (%/°C)	Nominal Operating Cell Temp. (°C)	Series Fuse Rating (A)	Connector Type	Frame Color	Back-Sheet Color	Length (In.)	Width (In.)	Depth (In.)	Weight (Lbs.)	Materials Warranty (Yrs.)	Power Warranty (Yrs.) 90%/80%
43.2	5.47	-0.49	-0.36	0.05	48	10	MC3	Silver	White	62.01	32.52	1.81	35.30	1	10/25
44.4	5.40														
35.8	7.79	-0.45	-0.33	0.03	47	15	Tyco			66.34	39.09	0.19	50.70	2	
36.1	7.95														
36.4	8.10														
36.5	8.15														
36.7	8.24														
60.0	5.90	-0.47			45	10	MC3		None	74.50	50.50	2.00	107.00	1	
60.0	5.90		-0.35												
60.0	6.05		-0.41												
61.9	6.20		-0.46			12									
62.5	6.40		-0.42	0.05											
63.2	6.50		-0.39												
63.8	6.50														

29.7	7.73	-0.45	-0.35	0.06	46	15	MC4	Black	White	65.28	32.83	1.81	37.50	5	12/25
29.9	7.83														
30.2	7.93														
30.4	8.03														
33.5	8.24	-0.50	-0.33	0.03	43		Tyco			58.31	38.94	1.87	37.92		
33.7	8.35														

43.2	5.20	-0.47	-0.34	0.04	DNR	DNR	MC4	Silver	DNR	62.20	31.80	1.65	35.30	5	25
43.6	5.25														
43.9	5.30														
44.2	5.35														
44.5	5.40														

12.7	7.89	-0.49	-0.36	0.05	48	15	MC	Black	Black	45.87	38.98	1.81	23.10	1	10/25
12.7	7.89														
21.8	7.99						J-Box	Silver	White	59.00	26.10	1.80	30.86		
21.9	8.20														
25.2	7.84						MC	Black	Black	45.87	38.98	1.81	31.96		
25.2	7.84														
43.1	5.46							Silver	White	62.00	32.50	1.80	37.49		
43.1	5.31														
29.0	8.02							Black	Black	52.30	39.10	2.30	36.40		
43.2	5.47							Silver	White	62.00	32.50	1.80	35.30		
43.2	5.47														
43.2	5.47														
44.4	5.40												37.50		
44.4	5.40												35.30		
29.3	8.22							Black	Black	52.30	39.10	2.30	36.40		
29.3	8.22														
44.8	5.60							Silver	White	62.00	32.50	1.80	37.50		
32.7	7.99							Black	Black	52.30	39.10	2.30	36.40		
32.9	8.23									58.70			39.60		
32.9	8.23														
36.0	7.90							Silver	White	64.60		1.80	44.10		
36.0	7.90														
36.3	7.99												46.30		
36.3	7.99												44.10		
36.5	8.10												46.30		
36.5	8.10												44.10\		
36.7	7.85														
36.3	8.35												46.30		
36.5	8.24												44.10		
36.5	8.24														
36.6	8.33														
36.6	8.33														
36.9	8.07														
37.0	8.24												44.00		
37.0	8.24														
37.0	8.40														
37.0	8.60							Black	Black						

Manufacturer	Model	Cell Type	Power @ STC (W)	Power @ PTC (W)	Power Tolerance (%)	Power Per Sq. Ft. (W)	Module Efficiency (%)	Max. Power Voltage (Vmp)	Max. Power Current (Imp)
Siliken www.siliken.com	SLK60P6L 215	Poly	215	192.4	+3/-0	12.3	13.2	29.0	7.41
	SLK60P6L 220		220	197.0		12.6	13.6	29.2	7.54
	SLK60P6L 225		225	201.5		12.9	13.9	29.3	7.68
	SLK60P6L 230		230	206.1		13.1	14.2	29.5	7.79
	SLK60P6L 235		235	210.7		13.4	14.5	29.5	7.97
Solarfun www.solarfun.com.cn	160-24-M165	Mono	165	147.2	+/-5	12.0	12.9	35.8	4.61
	160-24-M170		170	151.8		12.4	13.3	35.9	4.74
	190-27-M170		170	150.4		10.6	11.4	26.1	6.51
	160-24-M175		175	156.4		12.7	13.7	36.0	4.86
	190-27-M175		175	155.0		10.9	11.7	26.2	6.68
	160-24-M180		180	161.0		13.1	14.1	36.0	5.00
	190-27-M180		180	159.5		11.2	12.1	26.3	6.84
	190-27-P200	Poly	200	177.7		12.4	13.4	26.9	7.44
	190-27-P205		205	182.3		12.8	13.7	27.0	7.60
	190-27-P210		210	186.8		13.1	14.0	27.1	7.75
SolarWorld www.solarworld-usa.com	SW 165	Mono	165	147.4	+/-3	11.8	12.7	35.3	4.68
	SW 175		175	156.6		12.5	13.4	35.8	4.89
	SW 220		220	196.5		12.2	13.4	29.3	7.51
Solon www.solon.com	P220/6+/01 220Wp	Poly	220	194.3	+/- 3	12.5	13.4	28.8	7.65
	P220/6+/01 225Wp		225	198.9		12.7	13.7	28.9	7.80
	P220/6+/01 230Wp		230	203.4		13.0	14.0	29.0	7.95
	P220/6+/01 235Wp		235	208.0		13.3	14.3	29.2	8.05
SunPower www.sunpowercorp.com	SPR-210-BLK	Mono	210	188.9	+/-5	15.7	16.9	40.0	5.25
	SPR-215-WHT		215	195.5		16.1	17.3	39.8	5.40
	SPR-225-BLK		225	202.9		16.8	18.1	41.0	5.49
	SPR-230-WHT		230	209.5		17.2	18.5	41.0	5.61
	SPR-305-WHT		305	280.6		17.4	18.7	54.7	5.58
	SPR-310-WHT		310	285.0		17.7	19.0	54.7	5.67
	SPR-315-WHT		315	290.0		17.9	19.3	54.7	5.76
Suntech www.suntech-power.com	STP170S-24/Ab-1(Blk)	Mono	170	147.3	+/-3	12.4	DNR	35.2	4.83
	STP170S-24/Ab-1		170	147.5		12.4	13.3	35.2	4.83
	STP175S-24/Ab-1(Blk)		175	151.8		12.7	DNR	35.2	4.95
	STP175S-24/Ab-1		175	152.0		12.7	13.7	35.2	4.95
	STP180S-24/Ab-1(Blk)		180	156.2		13.1	DNR	35.6	5.05
	STP180S-24/Ab-1		180	156.5		13.1	14.1	35.6	5.05
	STP190-18/Ub-1	Poly	190	162.5		12.0	12.9	26.0	7.31
	STP200-18/Ub-1		200	171.4		12.6	13.6	26.2	7.63
	STP210-18/Ub-1		210	180.3		13.3	14.3	26.4	7.95
	STP260-24/Vb-1		260	231.3		12.4	13.4	34.8	7.47
	STP270-24/Vb-1		270	236.9		12.9	13.9	35.0	7.71
	STP280-24/Vb-1		280	246.0		13.4	14.4	35.2	7.95
Trina Solar www.trinasolar.com	TSM-165DA01	Mono	165	146.0	+/-3	12.0	13.3	35.6	4.65
	TSM-170DA01		170	150.6		12.3	13.7	35.8	4.76
	TSM-175DA01		175	155.1		12.7	14.1	36.2	4.85
	TSM-180DA01		180	159.6		13.1	14.5	36.8	4.90
	TSM-185DA01		185	164.3		13.4	14.9	37.5	4.95
	TSM-220PA05	Poly	220	192.9		12.5	13.9	29.8	7.39
	TSM-220DA05	Mono	220	193.6		12.5	13.9	29.8	7.39
	TSM-230PA05	Poly	230	202.0		13.1	14.6	30.0	7.66
	TSM-230DA05	Mono	230	202.7		13.1	14.6	30.0	7.66
	TSM-240PA05	Poly	240	211.0		13.6	15.2	30.6	7.84
	TSM-240DA05	Mono	240	211.8		13.6	15.2	30.6	7.84
UniSolar www.uni-solar.com	PVL-68	a-Si	68	61.4	+/-5	5.6	DNR	16.5	4.13
	PVL-124		124	112.0		5.8		30.0	4.13
	PVL-128		128	115.5		5.5		33.0	3.88
	PVL-136		136	122.8		5.8		33.0	4.13
	PVL-144		144	130.1		6.2		33.0	4.36
Yingli www.yinglisolar.com	YL175	Poly	175	148.9	+/-3	12.5	13.5	23.0	7.61
	YL 220P-29b		220	194.6		12.5	13.5	29.0	7.59
	YL 225P-29b		225	199.1		12.8	13.8	29.5	7.63
	YL 230P-29b		230	203.7		13.1	14.1	29.5	7.80
	YL 235P-29b		235	208.3		13.4	14.4	29.5	7.97

Open-Circuit Voltage (Voc)	Short-Circuit Current (Isc)	Pmp Temp. Coeff. (%/°C)	Voc Temp. Coeff. (%/°C)	Isc Temp. Coeff. (%/°C)	Nominal Operating Cell Temp. (°C)	Series Fuse Rating (A)	Connector Type	Frame Color	Back-Sheet Color	Length (In.)	Width (In.)	Depth (In.)	Weight (Lbs.)	Materials Warranty (Yrs.)	Power Warranty (Yrs.) 90%/80%
36.6	8.02														
36.7	8.10														
36.8	8.20	-0.43	-0.36	0.04	49	15	MC4	Silver	White	64.60	39.00	1.57	41.90	5	10/25
36.9	8.32														
36.9	8.47														
44.0	5.10					8				62.20	31.80				
44.5	5.12														
32.4	7.49					12				58.80	39.37				
44.8	5.17					8				62.20	31.80				
32.5	7.69	-0.40	-0.38	0.04	45	12	MC4	Silver/ Black	White/ Black	58.80	39.37	1.77	33.00	3	10/25
45.0	5.20					8				62.20	31.80				
32.6	7.78														
32.8	8.24					12				58.80	39.37				
32.9	8.35														
33.0	8.48														
44.0	5.10	-0.47								63.39	31.89		33.00		
44.4	5.30		-0.33	0.04	46	15	MC44	Silver	White			1.34		2	10/25
36.6	8.18	-0.45								65.94	39.41		48.50		
36.4	8.30														
36.6	8.40	-0.44	-0.35	0.05	DNR	15	Tyco	Silver	White	64.56	39.37	1.65	51.80	10	10/25
36.7	8.55														
36.9	8.65														
47.7	5.75		-0.29		46	15			Black						
48.3	5.80		-0.28		45				White		31.42		33.10		
48.5	5.87		-0.27		46	20			Black						
48.7	5.99	-0.38		0.06		20	MC4	Black		61.39		1.81		10	12/25
64.2	5.96				45				White						
64.2	6.05		-0.28			15					41.18		41.00		
64.2	6.14														
43.8	5.14			0.02				Black	Black				34.10		
43.8	5.14			0.04				Silver	White				34.17		
44.2	5.20	-0.48		0.02		15		Black	Black	62.20	31.80		34.10		
44.2	5.20			0.04				Silver	White				34.17		
44.4	5.40			0.02				Black	Black			1.38	34.10		
44.4	5.40		-0.34	0.04	45		MC4						34.17	5	12/25
33.0	7.89														
33.4	8.12									58.30			37.04		
33.6	8.33	-0.47		0.05		20		Silver	White		39.10				
44.0	8.09														
44.5	8.12									77.00		2.00	59.50		
44.8	8.33														
43.2	5.20														
43.6	5.25														
43.9	5.30					9				62.24	31.85	1.57	34.40		
44.2	5.35														
44.5	5.40														
36.8	8.00	-0.45	-0.35	0.05	47		Tyco	Silver/ Black	White/ Black					5	10/25
36.8	8.00														
37.0	8.18					15				64.96	39.05	1.81	43.00		
37.0	8.18														
37.5	8.38														
37.5	8.38														
23.1	5.10									112.10			8.70		
42.0	5.10									197.10			15.50		
47.6	4.80	-0.21	-0.38	0.10	46	8	MC	No Frame	Black		15.50	0.20		DNR	20
46.2	5.10									216.00			17.00		
46.2	5.30														
29.0	8.20									51.57			34.83		
36.5	8.15														
36.5	8.28	-0.45	-0.37	0.06	46	15	MC4	Silver	White	64.96	38.98	1.97	43.65	5	10/25
37.0	8.40														
37.0	8.54														

Web Extra

For more detailed descriptions of each specification, download "Specifications Details" at www.homepower.com/webextras

Rated power tolerance (%)

The range within which a module will overperform or underperform its STC rated power. This is a key specification to consider—it can be extremely disappointing if under even "ideal" conditions, your 2,000 W array may only produce 1,820 W if power tolerance is +/-9%. To be assured your module has the ability to produce the amount of power it is specified for, look for a narrow (or positive only) power tolerance. Note that while the "2009 PV Buyer's Guide" listed several modules with a +/- 9% power tolerance, the largest range listed in this guide is +/- 5%—a testament to improving PV module standards.

Rated power per square foot (W)

Also known as "power density," this value reflects power output at STC per square foot of module (not cell) area. This specification is also known as "power density." The higher the power density, the less space you need to produce a certain amount of power—if mounting space is limited, look for modules with a higher rated power density.

Module efficiency (%)

Output power divided by input power, or how efficiently a PV module uses the photons in sunlight to generate DC electricity. Like power density (above), the higher this efficiency, the more electricity you can generate in a given space.

Maximum power voltage (Vmp)

The voltage at which a module will put out the most power under STC. Temperature has a direct effect on module voltage, with higher temperatures resulting in lower voltage and lower temperatures resulting in higher voltage. String-sizing programs for grid-tied inverters take your site's high and low temperatures into consideration for optimizing the number of modules to be wired in series.

Maximum power current (Imp)

The maximum amperage produced by a module or array (under STC) when exposed to sunlight and connected to a load. This value is often used when performing voltage-drop calculations for wire runs from the PV array (see *Back Page Basics* in *HP133*).

Open-circuit voltage (Voc)

The maximum voltage generated by a PV module or array when exposed to sunlight, with no load connected. PV system components (modules, wiring, inverters, charge controllers, etc.) are each rated for a specific voltage, so maximum system voltage must be calculated using this value, as well as the number of modules in series in conjunction with the open-circuit voltage temperature coefficient (discussed below) and lowest expected temperature.

Short-circuit current (Isc)

The amperage generated by a PV module or series string when exposed to sunlight, with output terminals shorted together. This value is used to determine the wire and overcurrent protection sizes needed.

Maximum power temperature coefficient (% per °C)

The change in module output power at temperatures other than STC (25°C). This specification is used to calculate how much module power is lost or gained due to temperature variations. A-Si modules have lower values, not losing as much power as crystalline modules when hot.

Open-circuit voltage temperature coefficient (% per °C)

The change in module open-circuit voltage at temperatures other than STC (25°C). If given, this specification is used in conjunction with open-circuit voltage to calculate maximum system voltage for system design and labeling purposes (per *National Electrical Code* Article 690.7).

Short-circuit current temperature coefficient (% per °C)

The change in module short-circuit current at temperatures other than STC (25°C). These coefficients are much lower than temperature coefficients for voltage, and do not greatly impact most PV system designs.

Nominal operating cell temperature (NOCT)

The temperature of each module at an irradiance of 800 W per square meter and an ambient air temperature of 20°C. This specification is used together with the maximum power temperature coefficient to estimate power loss due to temperature increase.

Series fuse rating (A)

The amperage value of a series fuse used to protect a module from overcurrent, under certain conditions. Because PV modules are current-limited, there are some cases where series fusing may not be needed. Series fuses (if required) are placed in a combiner box or, in some cases, inside a batteryless inverter.

Connector type

The module output terminal or cable/connector configuration. Most modules come with plug-in weather-tight connectors (MC4, MC3, or Tyco), which makes installation easier. But some modules are returning to the J-box, since they allow the use of conduit between modules, a safety requirement for arrays installed in readily accessible locations.

Materials warranty (years)

A limited warranty on module materials and workmanship under normal application, installation, use, and service conditions. For the modules listed in this guide, warranties usually range from one to 10 years. This warranty usually guarantees full replacement or free servicing of a defective module(s) by the manufacturer.

Power warranty (years)

A limited warranty for module power output based on the minimum peak power rating (STC rating minus power tolerance percentage) of a given module. This warranty is usually separated into two time frames. Most manufacturers warrant for 10 or 12 years that their modules will operate within 90% of their minimum power rating, and for 20 to 25 years that the modules will operate within 80% of their minimum power rating. Longer warranty periods mean longer protection, but it is important to consider the potential longevity of the company offering the warranty.

Last Notes

While the PV module table continues to grow each year, in-the-field choices are often limited to models carried by your retailer or local installer. Before you buy, consider who will help you with warranty issues should you need support. If you purchase your modules online, you will likely have more difficulty with the warranty because you may have to deal with the manufacturer directly. Additionally, you will be responsible for removing the modules from the system, shipping them to either the retailer or manufacturer, and then reinstalling new modules. Installing dealers often can provide direct help with warranty claims, but ask your installer for details. "Free servicing and support" is often limited to a certain number of years after the original installation.

Access

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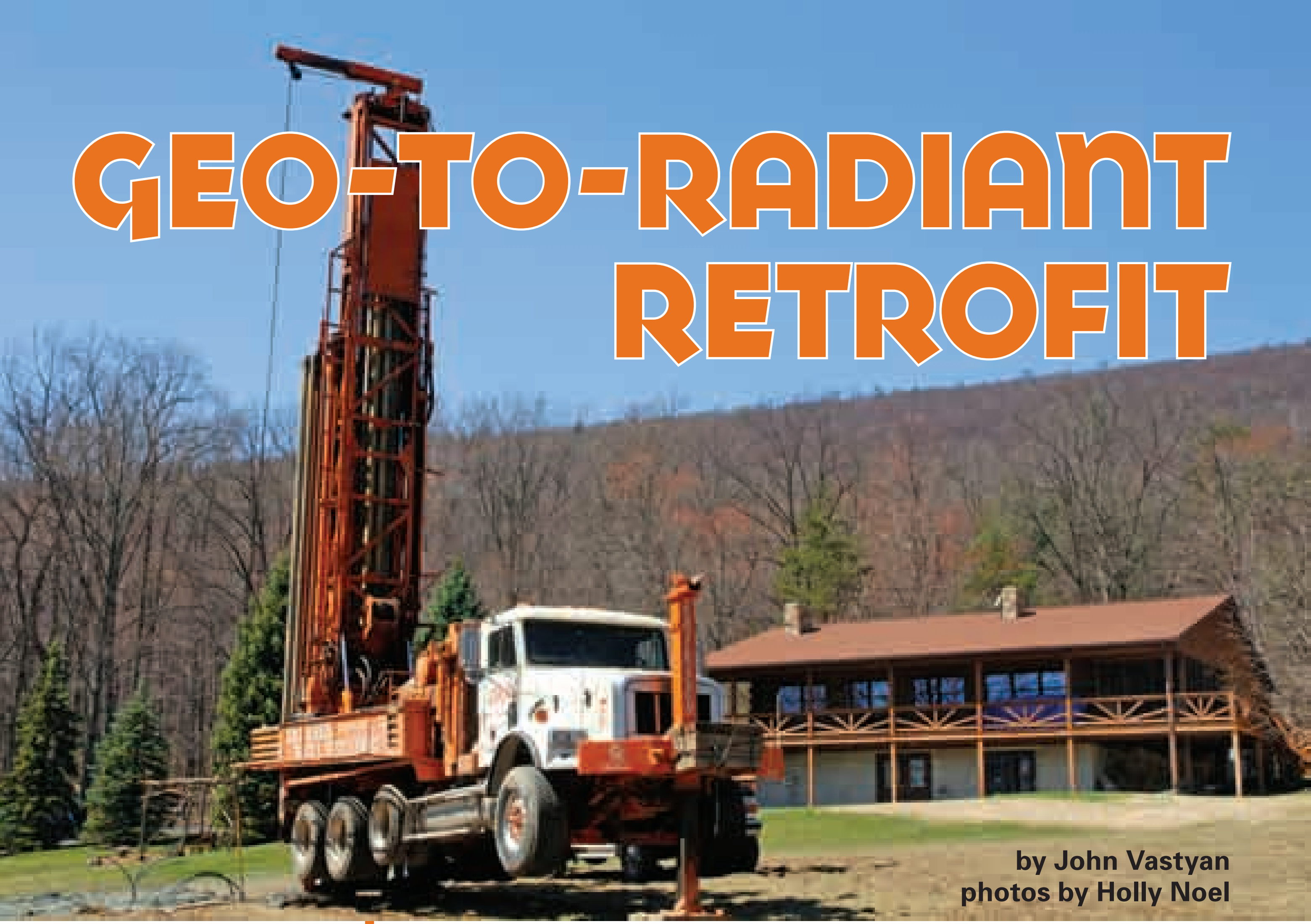


by John Vastyan
photos by Holly Noel

Three 300-foot-deep boreholes provide the thermal-coupling to the earth's stored energy. Geothermal heat pumps convert that thermal energy for use in space heating of the home, garage, and bunkhouse.

Some outdoor enthusiasts go to great extremes to set up the perfect camp. An example of just how far the Wengers will go is the "regreening" of their rural lakeside log home in west-central Pennsylvania.

Travis and Rachel Wenger spent most of the autumn months of 2007 shopping for a family retreat and hunting lodge. During a second visit to one of the properties—a 2,400-square-foot, three-bedroom log home built in 1994—their decision was made much easier by the arrival of a 400-pound harbinger. While they were admiring views from the home's deck, a black bear, ignoring them, had climbed up the other side of the deck to assault the gas grill.

Convinced it was "the sign we were looking for, we immediately agreed to buy the place," says Travis.

From Idyllic to Ideal

Nestled on a mountainside, the 16-acre home site borders thousands of acres of state game lands where deer, turkey, and bear roam freely. Nearby are several state parks, the Juniata River, and miles of wildlife trails.

While the property was just what they'd looked for, the home itself was less than ideal. "Before the remodel, the place left a Sasquatch-sized carbon footprint," says Dave Yates, the contractor hired to update the home's mechanical systems. "The log home leaked like a sieve. Winters are brutal up there, so they were burning LP gas furiously and getting dizzy watching the electric meter spin."

Yates visited the Wengers' retreat that fall to calculate the home's heating load and to take notes about the upcoming job, which included a geothermal-to-radiant space-heating system.

"For the homeowners, improving energy efficiency was just as important as having year-round comfort," adds Yates.

"The home had electric air-conditioning and a 140,000 Btu per hour propane furnace with supplemental heat from a fireplace and three old potbelly wood heaters," says Yates. "They also used several portable electric heaters and an old electric water heater."

The Wengers gave Yates a lot of flexibility in designing a "green" system, adding that if it made sense to keep some of the old equipment, fine; but where it made better sense to toss out the old to make room for the new…even better.

To prepare for the heating system overhaul, Travis and his father Merv, no strangers to remodeling jobs, added "truckloads of insulation," upgrading many of the walls to R-16 or better and the ceiling to approximately R-48, with plans to add a radiant barrier to interior trusses this winter.

By the time the contractor's crew began work at the home, 100 miles from their shop, the Wengers had already resealed all the logs in the home, began the basement remodel—including rigid-foam insulation—and set the foundation for the log garage, with a 150-foot, 4-foot deep trench from the house for an insulated loop to carry geo-to-radiant system heat between the two buildings.

The old 10-SEER (seasonal energy efficiency ratio) central air-conditioning system was disconnected and replaced with a 4-ton (48,000 Btu per hour) ClimateMaster Tranquility water-to-air system. Rated at 27-SEER—2.7 times the efficiency of the old air-conditioning system—this unit can also provide backup heat if needed.

For space heating, the Wengers settled on a unique mechanical system designed by Yates. For the heating season, the heart of this system is a high-temp, water-to-water ClimateMaster thermal hot water (THW) heat pump, two twin-coil Bradford White indirect water heaters that source heat from the heat pump system, and several preassembled HydroNex control panels by WattsRadiant—one of which is designed to accept solar heat for domestic water, then to share additional heat with the radiant system.

The heat pump system has a rated maximum output of 145°F with a peak coefficient of performance (COP) of

(continued on page 69)

Fred Umble of Creative Energy (left) hot-fuses geothermal pipe connections at one of the three well-heads.

Scott Barnett works on the new ClimateMaster water-to-air heat pump, rated at 27-SEER. This unit provides all cooling and supplemental heat.

Dave Yates does final soldering on the buffer tank that connects to the hydronic control panels in the background.

Travis's father, Merv Wenger, installs the Sea Tech "home-run" domestic water lines into the central manifold.

Geothermal Heating Basics

A few years ago, when "green" hadn't quite entered the mainstream vocabulary, and natural gas prices were continuing to climb, Tom and Cindy Shepherd saw the writing on the wall. They took out a home equity loan to pay for the installation of a geothermal heating and cooling system for the family's Indianapolis, Indiana, area home on the assumption that energy rates would quickly outpace interest on the loan. They were right.

Tom and Cindy spent several months researching the type of system best suited to their needs, interviewing installers and asking a lot of questions. An admitted "techno-junkie," Tom's job as a systems control technician for Honeywell became his trump card while he probed for answers.

With the help of Kris Kyler at Indiana Geothermal, a geo-loop contractor and geothermal equipment distributor, Tom and Cindy settled on a 4-ton (48,000 Btu per hour) water-to-air geothermal system to heat and cool their 3,600-square-foot, five-bedroom home. Their intent was for the new system to replace the 93% AFUE (annual fuel utilization efficiency) gas furnace and standard electric air-conditioning system.

The "geo" loops tap the earth's abundant energy through four 150-foot boreholes. "For the most part, it was a standard geothermal install," says Kyler. "And the benefit to the Shepherds' utility budget was immediate."

While many of their neighbors helplessly watch their utility bills soar higher, the Shepherds are enjoying record savings. In 2006, the Shepherds paid $3,620 for natural gas and electricity—energy used for space and water heating, air-conditioning, and pool heating. During the 12-month period following the installation, they paid $2,400 to accomplish the same thing—a 34% savings. The pool is also mostly heated geothermally, thus eliminating most gas heater operation, resulting in a further monthly savings of $100 to $400.

"Indianapolis Power and Light added to the savings by dropping our electricity rate from 4.4 cents per kWh to 3.8 cents because we installed the geothermal system," says Tom. "IPL also added a $50 rebate, and we picked up another $300 federal tax break."

"That played nicely into our overall savings on the loan," says Cindy. "With the rebate, the reduction in the electricity rate, and the energy savings, a substantial part of the loan payment is covered."

"The traditional heating and air-conditioning system that we had—considered to be high efficiency—was terribly inefficient when compared to geothermal, and rather uncomfortable," adds Tom. "Today, we have terrific comfort year-round and an expected seven-year payback on our investment."

Takes Little Area

The earliest geothermal systems tapped heat in the earth through pits or fissures that pushed hot water to the surface to heat homes and domestic hot water. Many of these systems used a very small pump to distribute the heat. These systems are site-specific and rare, but technology has vastly improved, permitting efficient geo-exchange from almost any plot of land. Modern systems use heat pumps to transfer heat for home space and water heating, and these systems will work in most climates. The difference in the systems is the cost of electricity to run the heat pump compressor and pumps—a good deal more electricity than used by natural geothermal systems.

A basement mechanical area is ideal for geothermal system components—equipment is protected and secure.

System Configurations

Trenched ground-source, closed loop

Bored ground-source, closed loop

Even if you have just a small patch of land, you might be able to use a geothermal system as a hedge against an energy crisis. Modern technology extracts thermal energy with greater ease, with little disruption to the surrounding landscape, and at high enough operating efficiencies to make payback shorter than ever.

Even though the installation price of a geothermal heat pump (GHP) system can be several times that of a similarly sized air-source system, the U.S. Department of Energy states additional costs are returned in energy savings in five to 10 years. System life is estimated at 25 years for the indoor equipment and 50 or more years for the ground loop.

A ground-source unit works like a conventional heat pump to cool a home in the summer, and heat it in the winter. The key difference between an air source heat pump and ground-source is that the ground-source unit harvests the stable and renewable heat from beneath the earth's surface, whereas air-source relies on widely varying air temperatures to do the same job. As with any heat pump, geothermal and water-source heat pumps provide space heating and cooling, and can also supply the house with hot water.

Depending on latitude, ground temperatures range from 45 to 75°F. Like a cave, this ground temperature is warmer than the air above it during the winter and cooler than the air in the summer. The GHP takes advantage of this by exchanging heat with the earth through a ground heat exchanger using a liquid transfer medium such as water or an antifreeze solution.

On larger lots where there is ample property to excavate, the geo-exchange field can be trenched instead of drilled—a less expensive method than drilling holes.

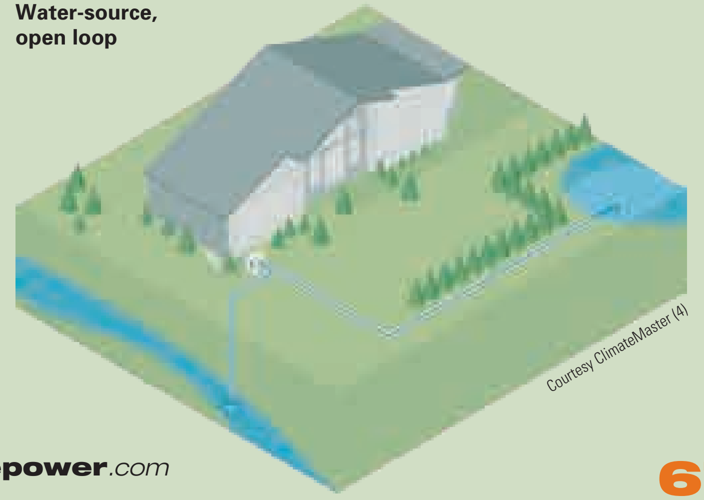
If a pond is present, a water-to-water geothermal system may be able to tap this thermal sink by running "slinky lines" from a trench into deep water.

Because a GHP harvests energy from the earth, less fossil-fuel-based energy is used, which reduces greenhouse gas emissions and can cut utility bills by up to 70%, says Tony Landers of ClimateMaster. And very little maintenance is required because the stable heat source avoids thermal stresses to the compressor and the enclosed unit is inside, protected from the weather.

The Shepherds' geothermal system taps the earth's constant temperature of about 51°F in Indianapolis. From the variety of loop configurations available for a geothermal system, the Shepherds and Kyler—like the Wengers—chose the closed-loop borehole method, which disturbs the least amount of earth. For homes where ground space is limited, or for homes with

Water-source, closed loop

Water-source, open loop



Courtesy ClimateMaster (4)

mature landscaping, this configuration is ideal because all evidence of the drilling can be removed, and lines are buried.

"Most geothermal systems supply three or four units of heat or cooling for every unit of electrical energy input," says Kyler, who has installed geothermal systems for more than 20 years.

Open- & Closed-Loop Systems

Electricity is used only to power the equipment says Tony Landers, marketing director for ClimateMaster, a manufacturer of geothermal systems. "The rest of the process uses the free, clean, and renewable energy that's tapped just below the earth's surface."

There are two basic types of water-source geo systems: open-loop and closed-loop. An open-loop system typically pumps water out of a deep well, extracts heat from it, and injects it back into another well, a pond, or a river. An open-loop system tends to be more efficient because it pulls the heat out of a steady stream of water from deep in the ground. But open-loop systems are prohibited in many parts of the country because of water quality and water conservation concerns.

A closed-loop system uses a continuous loop of plastic tubing as a heat exchanger. The tubing is connected to the indoor heat pump to form a sealed, underground loop through which a glycol or alcohol antifreeze solution is circulated. Unlike an open-loop system that consumes water from a well, a closed-loop system recirculates its heat-transferring solution in the pipe. Closed-loop systems can be trenched, "bedded" (in an excavated, flat, deep bed) or drilled.

Doing the Work of Three

A geothermal heat pump system typically replaces two systems: heating and air conditioning. A geo system uses ground water or the earth as a source of heat in the winter by pulling heat from the water or ground, and using water or ground as a place to "sink" heat in the summer. The final process of thermal exchange takes place in mechanical equipment that serves both heating and cooling needs for a building. Typically, a system distributes the heat through a conventional forced-air ducted system, or through hydronic tubing in the floor like the Wengers' system.

Many systems can also heat a home's domestic water by either integrated water preheating or through "desuperheating." A desuperheater reclaims heat from the air-conditioning cycle to heat water by transferring the compressor's waste heat to a hot water storage tank, and can reduce water-heating costs in the summer by 40 to 60%, according to Landers.

Geothermal systems are not without their disadvantages, which mainly center on installation time and up-front costs. With many pieces and components to set up and integrate, the installation is more complicated and involved and, therefore, more time-consuming.

And, compared to other space-heating methods, geothermal systems are also more expensive. However, Yates points out that it's not the equipment that eats up the budget but the preparation—outside drilling and trenching, and fusing the pipes—and connecting the many systems that take heat from the heat pump.

—John Vastyan

Geothermal vs. Conventional HVAC & Water Heating System

Year	Projected Propane Cost ($/gal.)	Projected kWh Cost	91% Efficiency HVAC System[a]	Geothermal Heat Pump[a]	Yearly Savings	Annual ROI[d]
1	$2.99	$0.110	$4,966[b, c]	$1,725[c]	$3,241	28.1%
2	3.14	0.116	5,214	1,811	3,403	29.5%
3	3.30	0.121	5,475	1,902	3,573	31.0%
4	3.46	0.127	5,749	1,997	3,752	32.6%
5	3.63	0.134	6,036	2,097	3,940	34.2%
6	3.82	0.140	6,338	2,201	4,136	35.9%
7	4.01	0.147	6,655	2,311	4,343	37.7%
8	4.21	0.155	6,987	2,427	4,560	39.6%
9	4.42	0.163	7,337	2,548	4,788	41.5%
10	4.64	0.171	7,704	2,676	5,028	43.6%
11	4.87	0.179	8,089	2,810	5,279	45.8%
12	5.11	0.188	8,493	2,950	5,543	48.1%
13	5.37	0.198	8,918	3,097	5,820	50.5%
14	5.64	0.207	9,364	3,252	6,111	53.0%
15	5.92	0.218	9,832	3,415	6,417	55.7%
16	6.22	0.229	10,324	3,586	6,738	58.5%
17	6.53	0.240	10,840	3,765	7,075	61.4%
		Total	$128,319	$44,569	$83,750	

Table Parameters:

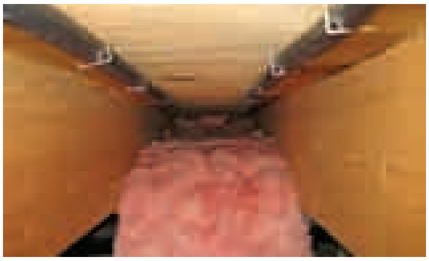
The table compares a 4-ton ClimateMaster Tranquility geothermal heat pump to a 91% efficiency, propane-fueled condensing system, electric air-conditioner unit, and electric water heater.

[a] Yearly costs include space and water heating, cooling, a blower, and domestic water heating. Assumptions were a heat loss of 59,602 Btu/hr. and a heat gain of 25,940 Btu/hr.

[b] Assumes a propane cost of $2.99 per gallon for the first year, with a 5% annual increase.

[c] Based on an initial electricity rate of 11 cents per kWh, with a 5% annual increase.

[d] Calculated using the added cost of the GSHP compared to a conventional heating system. Installation costs were $29,503.60, with 30% tax credit subtracted. A conventional HVAC system price was estimated at $17,977; the added cost of GSHP was $11,526.60, which includes loop, piping, etc.)



Left: Dave Yates installs hydronic radiant tubes to the underside of the garage subfloor.

Above: Insulation directs radiant heat upward to the room above.

Right: Homeowner Rachel Wenger ties radiant tubing into place before the garage workshop's concrete floor is poured.

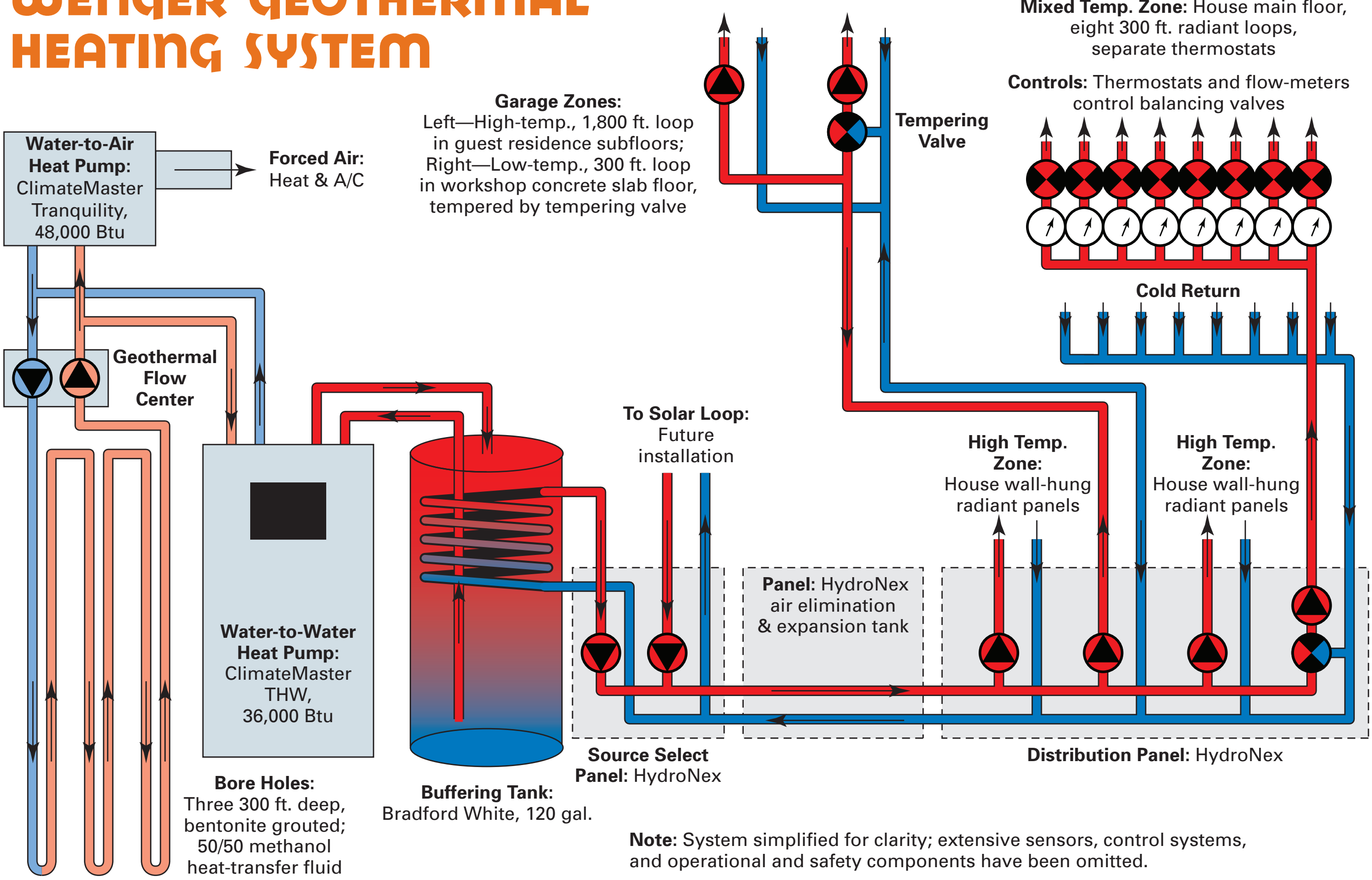
4.5, assuming sufficient geo-exchange, which required three 260-foot boreholes. The COP means that for every unit of (electrical) energy used to operate the system, 4.5 units of heating/cooling are available.

But the Wengers asked geothermal driller Dave Eriksen to drill down farther, lengthening each run by another 40 feet. "I knew from a friend's geothermal system that their heating needs would occasionally max out the field's capability," says Travis, "so by adding 15% or so to the field size, I figured we'd have an underground insurance policy."

Eriksen drilled three holes into which geothermal pipe was inserted. The holes were also thermally grouted, a process that injects a bentonite slurry to enhance temperature exchange between the pipe and earth.

"We believe this was the reason for one of the big surprises we had with the system's startup in December 2008," says Yates. "Though outside temperatures hovered between 10 and 12°F, the THW unit delivered system heat of 157°F—substantially higher than what it was rated for."

WENGER GEOTHERMAL HEATING SYSTEM



Note: System simplified for clarity; extensive sensors, control systems, and operational and safety components have been omitted.

Dave Yates installs backup Fujitsu minisplit heat pumps, which also provide air-conditioning for interior garage spaces.

Radiant Details

All of the home's PVC plumbing—which, according to Yates, was a "snake pit of code violations"—was replaced with WaterPEX lines that connect to a central Sea Tech manifold in the new mechanical room.

While the basement remodeling was underway and the joists were accessible, the Wengers' crew stapled 2,400 lineal feet of Onix radiant-heat tubing to the subfloor to heat the home's main floor. The eight 300-foot loops were attached to manifolds with balancing valves and flow meters for precise control of heat distribution. "The Onix tubing flexes like rope, can be doubled-up and pushed through joist bay holes, and flattens slightly during staple-up, greatly improving heat transfer," says Yates.

While the subfloor tubing was being attached, the crew mounted the control panels, which temper system water based on outdoor temperatures. "We designed the system so that the 36,000 Btu water-to-water geothermal unit sends heat directly into a 120-gallon, two-coil indirect water heater next to it," says Yates. "This was the heat pump's 'thermal target,' which efficiently exchanges heat that then moves to the control panels."

Heat exchangers separate the geothermal system's 50/50 methanol solution—a special antifreeze chosen for stability and heat exchange properties—from the water systems within the home. "We run the system all winter long," says Travis, "so we didn't need to circulate an antifreeze solution within the radiant tubing."

The home's hydronic heating requires two water temperatures: a lower temperature for the floor loops (in three zones, each with a separate thermostat) and a higher temperature for several wall-hung radiant panels and the underground loop to the garage.

"The hydronic control panels—in the house and garage—came preassembled, with all the controls and components needed for low- and high-temp heat distribution," says Yates, "saving weeks of labor."

Rigging the Radiant System

"We could meet a lot of needs with the THW heating the 120 gallons of water in the main source tank between 145 and 155°F, but it couldn't exceed 36,000 Btu," says Yates. "So we had to choose carefully what and how to heat, and had to insulate real well in all directions. With house needs met, we still had plenty of Btu to heat the injection loop to the garage."

Heated water is sent to the garage loop via R-flex, a polyethylene-insulated, tandem underground PEX pipe. The subterranean tubing thermally connects the house buffer tank's 120-gallon volume with the garage's slightly smaller, two-temperature radiant heat system.

In heating mode, high-temp water (145 to 155°F) from the buffer tank enters the garage's control panel and then supplies two radiant zones. Water at about 125°F is sent through the 1,800 lineal feet of tubing that heats the guest quarters, and 90 to 110°F water is sent through the single, 300-foot loop of tubing embedded in the tool room's 10-by-30 foot concrete slab.

The stapled-up tubing's heat is directed upward by R-19 batting insulation below the tubing. By applying many layers of R-19 fiberglass batts, and 2-inch rigid insulation, the Wengers achieved R-90 in the ceiling and upper kneewalls of the garage.

"The massive dose of insulation started when we needed to thermally protect the long radiant supply and return tubing runs in one of the kneewalls," says Merv. "We made a cocoon for the tubing that was as long as the garage and just kept adding layers. We had a good source for the material, so we decided to buy a good bit more than we'd need, knowing that it could only help to keep heat in the building."

The only thing they didn't ask of the geothermally heated water was to heat domestic water for the guest quarters' sinks and shower, so an electric, 30-gallon tank-type water heater was placed in the radiantly heated tool room, directly below the shower.

Phase I Performance

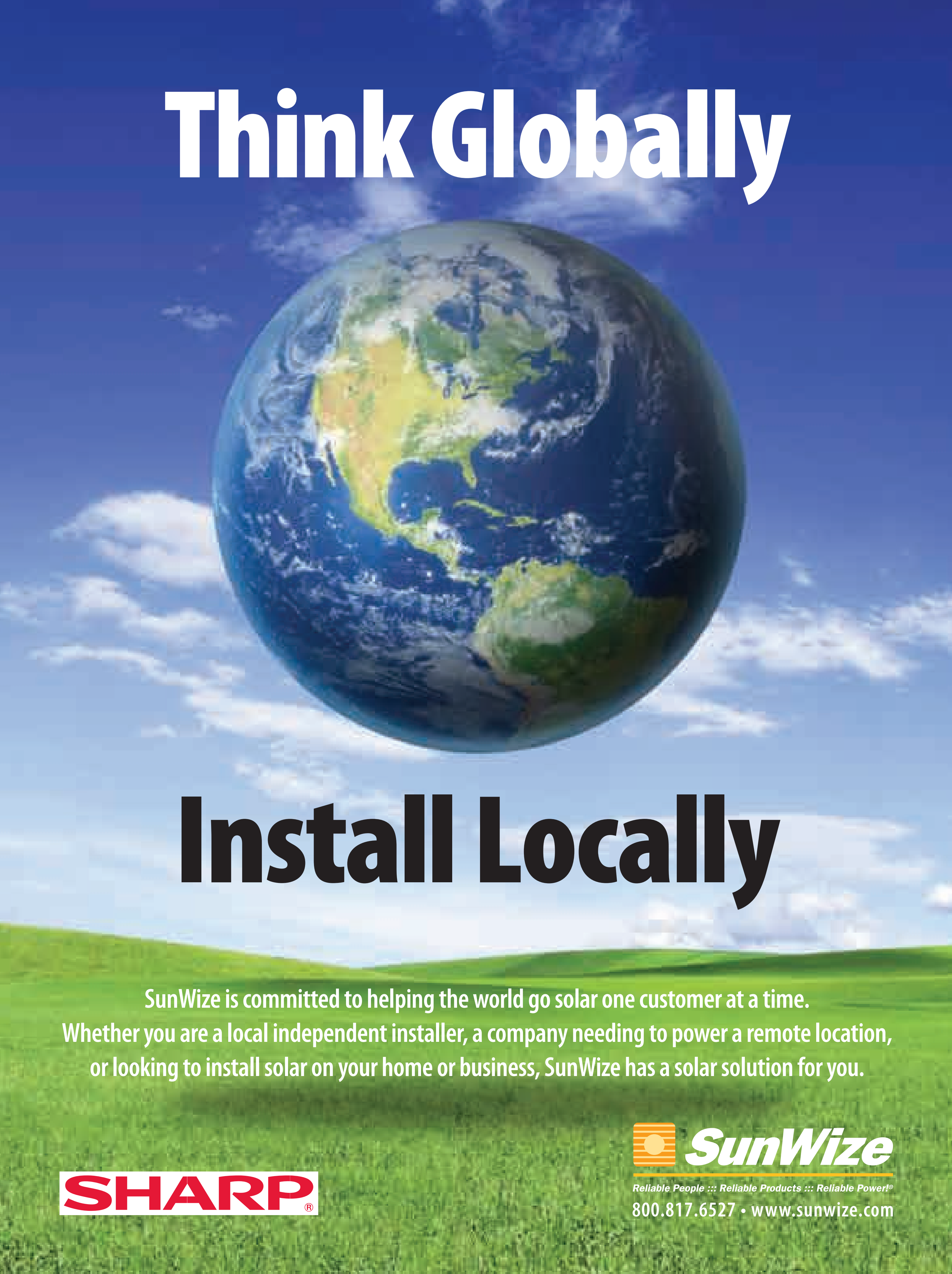
Just before their first full heating season, the Wengers added more insulation in the ceiling of the home's main floor and replaced the potbellied stoves with a more efficient, small, centrally located Vermont Castings wood heater.

"Last winter was amazing," says Rachel. "Even though all the systems weren't operational, we had plenty of heat for the house with the geo water-to-air heat pump, the new wood heater, and a little electric radiant heat that we used. This winter will be the first for the home's main radiant system and the garage radiant, but we've prefired all parts of the system and everything went well. The thermostats are set, so all we need now is for the outdoor temperatures to drop."

"Based on our preliminary calculations and the performance we've seen so far, the Wengers will probably see a 60 to 80% drop in their energy expenses," says Yates. "The carbon footprint got a lot smaller, while they've added tremendously to the size of their comfort zone!"

Access

Manheim, Pennsylvania-based John Vastyan is a journalist and communications professional who focuses on the plumbing, mechanical, radiant heat, and geothermal industries. He can be reached at 717-664-0535.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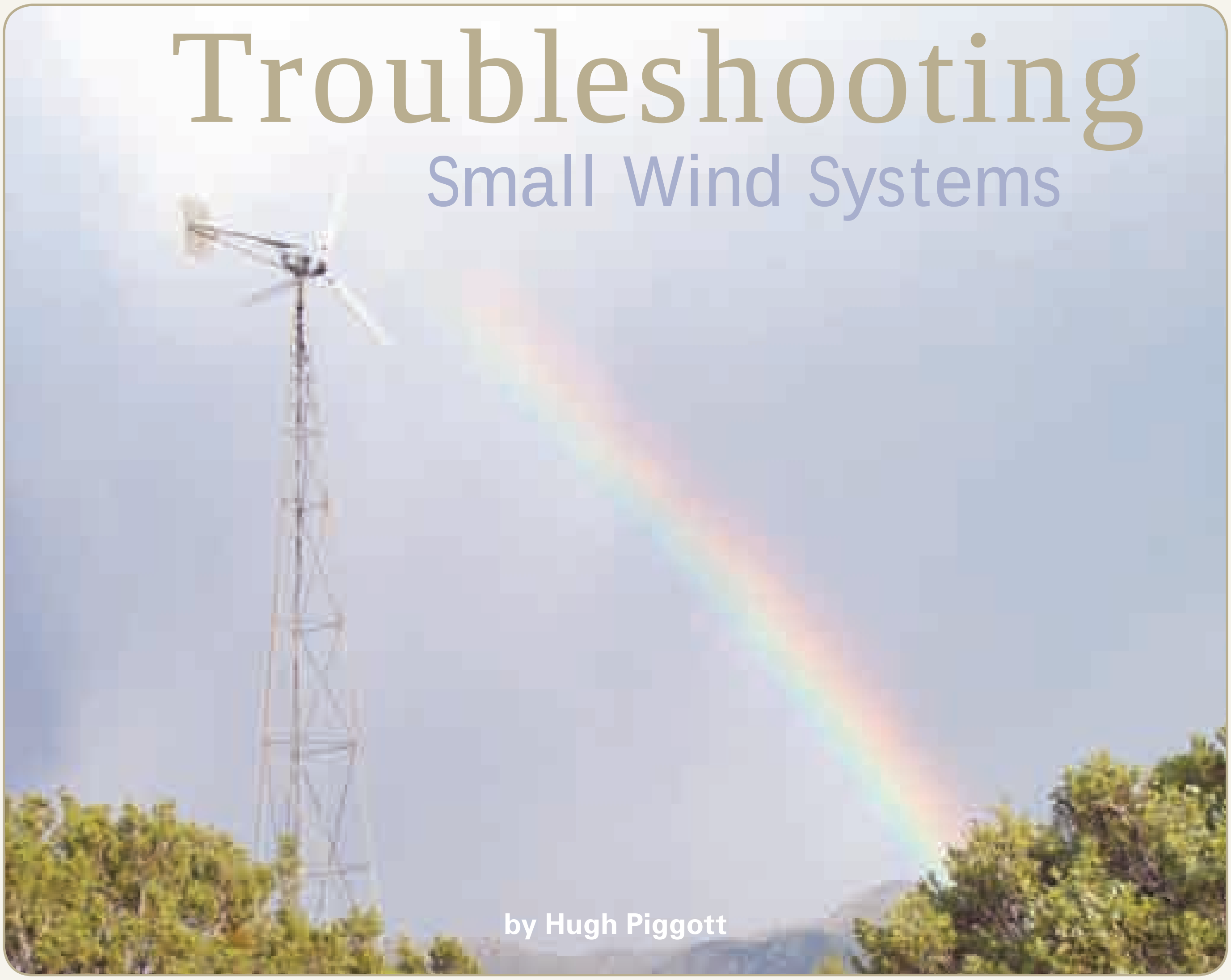
Troubleshooting
Small Wind Systems



by Hugh Piggott

Courtesy Grey Chisholm

Putting a collection of moving and electrical parts on the top of a tower where it is exposed to the whims of the weather can be asking for trouble. Here's what to do when something goes wrong with your wind turbine. Reasons for a turbine's poor performance fall into the following problem categories:

- System Design
- Aerodynamic
- Mechanical
- Electrical
- Controller

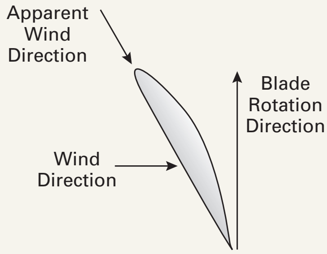
SYMPTOM: NO OUTPUT & WIND TURBINE RUNS VERY SLOWLY OR IS STOPPED

There may be **insufficient wind**. Wind comes and goes, and it is normal to see a wind turbine idle at times. But if it rarely turns, you need to consider whether it is appropriately sited. Does the tower place the turbine 30 feet or higher above any obstacle within 500 feet? Or is it attached to a rooftop or sitting lower than or level with nearby objects?

Just as you would not place a PV module in the shade, you should not site wind turbines in sheltered places. Wind energy is extremely sensitive to wind speed, and wind speed is very much affected by obstructions. A tall tower is almost always essential for good results. If you wish to study the wind speed at your site, low-cost data-logging systems with anemometers are available.

Perhaps the **blades are fitted incorrectly.** Check that the convex side of the blade is on the downwind side of the turbine. In an airplane wing, this would be the upper surface—the side that lifts the plane.

Blade Orientation



That same lift-force pulls the blade around and its reaction slows the wind. The angle of the blade to the wind is also critical. Check that the blades have been installed according to the manual.

Mechanical problems are usually easy to diagnose. If the blades refuse to budge in a good breeze, something is likely locked. Maybe a main bearing has failed and seized up, or a magnet has come loose and jammed the alternator. Another possibility is that the alternator is iced up. If the blades spin, but slowly, make sure the turbine is facing into the wind. If not, the yaw bearing on which it pivots may have failed or the tail may be stuck in the furled position.

An electrical short-circuit will disable the wind turbine. In the event of a short-circuit, turbines with permanent-magnet alternators deliver a high current. This produces a high torque against the rotation of the turbine, which prevents it from running at normal speed. Many turbines have brake switches that deliberately short-circuit the output for control purposes. If the blades turn very slowly, start by checking if the brake switch is closed.

Symptoms of Troubled Turbines

Diagnosing the cause of a turbine's problem may be the most difficult part of addressing the problem. Sometimes the component where symptoms appear may be separate from what's actually causing the problem. (Note that this article addresses problems specific to permanent magnet based turbines only.)

Example Symptoms & Their Causes

SYMPTOM: Noisy blades.
PROBLEM: The machine is overspeeding (blades spinning too fast) due to an electrical problem.

SYMPTOM: The tail shakes and comes loose.
PROBLEM: The blades are out of balance.

SYMPTOM: Low power output.
PROBLEM: The tail is furling at too-low wind speeds.

Using a Multimeter

A multimeter allows you to "see" what is going on in the electrics and track down a problem. An inexpensive meter can be used to measure the voltage between two terminals, but beware of inaccurate readings if the meter's battery begins to run low. Select an appropriate AC or DC voltage range depending on whether the measurements are before or after the rectifier. For a voltage reading, make sure that your leads are plugged into the "COM" and the "V" sockets (not "A," which is for measuring current).

The AC voltage coming from the alternator should be about 70% of the DC voltage of the battery or inverter. (The rectifier will output only the peaks of the AC.) So it is normal to see readings of 17 to 20 VAC in the wiring of a turbine that is charging a 24-volt battery bank (at 24 to 28 VDC).

Normally you will find three AC wires. Check that the voltage between each pair is the same. If the voltage is higher on one wire, there may be a break between this point and the rectifier, or some blown diodes. If there is no voltage between two of the wires, they are probably shorted together somewhere.

Some turbines (the Bergey XL.1, for example) have the rectifier on the turbine, so you will see DC voltages between the two wires. Also be aware that the XL.1 has a controller that boost voltage to improve performance in low winds. So do not expect to see full battery voltage at times.

Courtesy Hugh Piggott (2)

They can be pricey, but clamp-type current meters (or clamping probes for multimeters) are the ideal troubleshooting tool. Select one with a DC range to trace short-circuits in small wind systems where the turbine is turning very slowly. Clamp the tongs over each wire and you will "see" slow pulses of current in the ones leading to the short-circuit. If the turbine is running fast and vibrating, your clamp meter can reveal which wire is not conducting current.

Checking a Rectifier

A rectifier is an assembly of diodes that allows current in one direction only. There will be two or three AC terminals and two DC terminals. Within the rectifier, there are two diodes from each AC terminal—one to each DC terminal—that allow a flow of charge toward the positive or away from the negative to create a DC output in the correct direction.

Use a multimeter to test each diode. First, shut down the turbine and disconnect the battery—be sure to wait until the turbine is braked. Next, disconnect all of the wires from the rectifier, taking care to identify them clearly for reconnection. Set the multimeter to the diode test position, usually marked with a diode symbol.

Touching the meter probes to each end of a diode will give three possible readings:

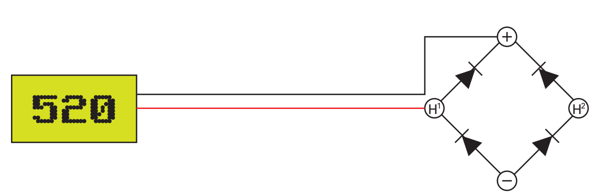
- Open circuit (usually indicated by a digit 1 on the left-hand side of the display, or the letters OL)
- Diode forward voltage (usually a number around 500 mV)
- Short-circuit (usually 0.0)

A properly functioning diode will give an asymmetrical outcome—open circuit one way and a forward voltage the other way. A short-circuit or an open circuit in both directions indicate a bad diode.

Place the red probe on the positive DC terminal and check with the black probe on each of the AC terminals in turn. You should see open circuit (top right photo). Now try reversing the probes and place black on the positive DC. You should get a number on the display each time you touch the red probe to an AC terminal. Check the negative DC terminal in the same way and you should see the exact opposite (bottom right photo).

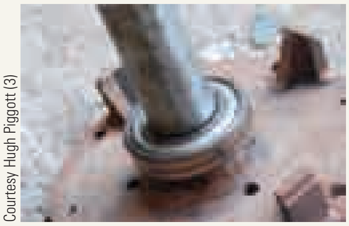
If you find a shorted diode or one that is open in both directions, the rectifier needs to be replaced. Consider possible causes, including overcurrent, overheating from poor connections, and lightning surges. Replacing your rectifier with one that is made for higher voltage and current may prevent similar problems from occurring in the future.

Courtesy Hugh Piggott (2)



Courtesy Ian Woofenden

This winding from an alternator is blackened from overheating and the insulation has failed.



Courtesy Hugh Piggott (3)

This ball bearing is getting old and noisy.

Turbines mounted on a rooftop do not capture enough wind to make them worthwhile.

Measure the output voltage of the turbine if you can, between the rectifier and the turbine. If the voltage between any two of the circuit wires is zero, suspect a short-circuit in the wiring (maybe the brushes) or the alternator. A pulsating or "lumpy" torque holding back the blades indicates a short between two of the three wires.

A low-tech test for finding short-circuits is to disconnect the wires at the base of the tower. If the turbine still does not start, then the short is above—maybe in the slip rings or the tower wiring. If the turbine does start, then the short is elsewhere (maybe in the rectifier or controller). The best tool for tracking down a short-circuit is a clamp-on current meter. Check for current at different points in the system. If there is no current at the point of measurement, the short-circuit is somewhere closer to the turbine. If you do measure a current, then the fault is farther away from the turbine. Be aware that the current from a slow-turning alternator may be more like a series of DC pulses than a steady AC current.

If no current is found, there may be a short-circuit failure of the alternator windings. Excessive current can burn out the coils. High-voltage alternators can suffer insulation failures in wet conditions, leading to the same condition. In both cases, the alternator becomes stiff to turn due to internal currents, even when disconnected.

Tracing the current may lead you to a blown diode in the rectifier (see "Checking a Rectifier" sidebar). Another possibility is multiple grounding. If the battery negative is grounded, and one of the AC phases is also grounded, then other phases will be shorted to the ground by the rectifier during the negative half of their cycle.

This tower barely lifts the turbine above the treetops, which can compromise performance.

Another cause of stalling can occur if battery voltage falls to below half of its nominal value due to heavy battery discharge or failure—the turbine will be loaded with current at low speed and the blades will stall, preventing the turbine from reaching operating speed.

Control problems can manifest in several ways, like a broken spring in the blade pitch-control, a jammed tail-furling system, or maybe the electronic control system is stopping the turbine.

In some cases, the controller at the battery or inverter limits the voltage by diverting AC power directly from the turbine to a dump load. A faulty or blown controller can apply the dump load full-time, drawing a current that stalls the turbine. In some hybrid system cases, a solar-electric array can push battery voltage up enough to activate a dump load on the wind turbine, and stop it from working.

SYMPTOM: NO OUTPUT & THE TURBINE IS RUNNING FAST

There may be **too little wind.** Small wind turbines have to run at a relatively high speed before they start to produce power. Their voltage is proportional to speed, and they have to achieve the required cut-in voltage for battery charging or, in the case of batteryless grid-tie, the minimum needs of the inverter.

The turbine may have become **disconnected from the load** (battery, controller, etc.) so that there is no circuit for current. No current means no torque to hold back the blades, and they will run fast, like an engine in neutral on full throttle. The turbine may spin faster than its components are designed for, and turbine voltage will be high. Higher-than-normal voltage can harm system electronics (controller, inverter, etc.) and be a danger to humans. Measure the voltage in different parts of the system (being careful of shock from bare wires or terminals). If it is abnormally high, there is a break (open circuit) between the point of measurement and the load end of the circuit.

The best course of action is to immediately apply the short-circuit brake and investigate the wiring. If the wind is not too strong, then the turbine should stop. If the brake

fails to stop the turbine, then carefully short-circuit the wiring at the base of the tower. If the turbine wiring has become disconnected at the tower top, the short-circuit will not stop it, and unless there is a functioning mechanical shutdown system you will have to wait for the wind to stop.

If the brake does work, then make sure fuses, circuit breakers, and connections are conducting properly. If the turbine was disconnected from its battery, but remained connected to the system electronics, then the inverter and controller will have been exposed to excessive voltages and may be damaged. Always wire the turbine with its own separate fuse at the battery.

A broken connection in one of the DC wires will leave the wind turbine freewheeling. But there are usually three wires in the AC cable—if one is broken, the turbine will be noisy; if two are broken, it can run free.

Courtesy Hugh Piggott

Slip-rings and brushes, and the tail-furling hinge on an AWP turbine. Slip-rings are a common trouble spot.

SYMPTOM: LOW ENERGY PRODUCTION

Poor system design can lead to a chronic energy shortfall. As a rule, a small wind turbine can produce about 20 kWh of energy per annum per square foot of swept area, given a site with 10 to 11 mph average wind speeds.

For example, a turbine with diameter of 8 feet would have a swept area of about 50 square feet and might produce about 1,000 kWh per year, given this average wind speed. All too often, deceptive turbine marketing fosters unrealistic expectations. There may be nothing wrong with the turbine, other than a lack of wind or unrealistic expectations that resulted from marketing hype.

Undersized wiring on a long run also could mean that much of the energy is lost in the wire run.

Incorrectly fitted blades can impair performance and reduce output. But in most cases, the assembly of the turbine is simple and unambiguous. Worn or damaged blades become less efficient at capturing the wind. Another symptom of this problem can be a shaking and rattling machine. A buildup of ice or insects can also have these effects.

Mechanical problems such as failed bearings in the alternator will manifest as noise long before they affect energy production, but a jammed yaw bearing could prevent the turbine from turning to face the wind. Check that the turbine is tracking the wind direction properly.

Electrical issues can certainly impact energy production. A blown diode in the rectifier or a bad connection in one wire also would impact performance. These faults produce a growling vibration in the machine and uneven voltages and currents in the three wires.

Control issues can impair performance when, for example, the turbine furls before it can produce its rated output. But some control systems will only allow the output to reach a peak in a very specific wind speed. Blink and you could miss it! It's hard to tell whether the control system is working correctly; if in doubt, check for mechanical damage such as worn bushings on the control systems or broken springs.

Troubleshoot & Save

It is worthwhile to know how your system works, and to take an interest in its behavior and misbehavior. You may not be able to understand it as well as the manufacturer, designer, or installer, but you have the advantage of being on site.

Hiring an expert to fix a simple problem can be expensive—even if only for travel. Being able to diagnose the fault correctly, so that the right part arrives to fix the problem, can save a lot of money. Plus, you'll get the satisfaction of taking responsibility for—and maintaining—your own electricity supply.

Access

Hugh Piggott (hugh@scoraigwind.co.uk) has been troubleshooting wind-electric systems for more than three decades at his home in northwest Scotland and around the world.

DIY PV

by Bob Inouye
photos by Carol Inouye

Bob Inouye decided to install his own grid-tied photovoltaic system.

Have you ever wondered whether installing a grid-tied solar-electric system could be a do-it-yourself project? My wife Carol and I had made some of the easier energy-efficiency upgrades to our home, and even installed a domestic solar hot water system, so it was time to tackle our electricity needs. But the prospect was daunting. Most people will cede that installing a PV system is a much bigger undertaking than putting in a solar hot water system. Plus, it's more expensive and requires more room.

The learning curve is steep, and I started with *Home Power* articles, progressed to attending a helpful seminar presented by Power Trip Energy of Port Townsend, Washington, and then reached a decision point: Were we going to hire a professional to install a system, or tackle the design and installation ourselves? Ultimately, the decision was made easier because there are no installers in our area. An out-of-county company gave us a quote of $53,000 for a 5.9 kW, ground-mounted, grid-tied system that would offset most of our household's yearly electricity needs. About that time, with the national economy taking a nosedive in early 2009, our comfort level with a very large PV investment also dropped. It was time to consider cutting costs by taking on the project ourselves—*if* a DIYer could actually make it happen.

Thus began several months of intensive research, a step that cannot be taken lightly. Next, I researched Internet sellers of PV components for current specs and prices. Since I'm not an electrician, I had doubts about tackling the complexities of both high-voltage DC and AC systems, but after careful reading of John Wiles' *Code Corner* columns and Article 690 of the *National Electrical Code Handbook*, those elements started to make sense. Even at this early stage, it was evident that the savings could exceed $10,000. By the time we were done, the savings were more than twice that.

Jumping Hurdles

This kind of project should only be undertaken by someone ready to do the homework and learn the skills. If you are considering a DIY PV system, be aware of some major hurdles:

Need analysis: Review your electricity bills. Reduce your electricity consumption where possible. Determine how many kWh of electricity per year you'll need.

Site analysis: Find true south at your site. Analyze your exposure to the sun's path, and, ideally, seek a location that's shade-free during the entire year. Determine how many peak sun-hours your location receives in an average year. (For more information on siting a PV system, check out "Solar Site Assessment" in *HP130*.)

Mounting system: Evaluate the roof's available space, orientation, pitch, and structural soundness, and the condition of your roofing material. Are there shade-free options for a separate pole-mounted or ground-mounted system? What are the respective costs, installation time, durability, and visual considerations for each mounting option?

All in the family—Martha Inouye, the author's niece, was an integral part of the system installation team.

Do you have the tools and skills necessary for your project's specific installation needs?

System design: What type of PV modules best suit your situation? How can you ensure a good match between the PV array and the inverter(s)? What other components—such as combiner boxes, disconnects, overcurrent protection, and metering—are necessary for a code-compliant, efficient, and safe system?

Rebates and other financial incentives: What federal, state, and local incentives are available? Do they require purchasing locally manufactured components? Are incentives structured as up-front rebates, tax credits, or paid out over time? Do they require that a licensed professional install the system?

Permitting: What permits does your local jurisdiction require for this project? Will you need a building permit for roof work or ground-mount construction? An electrical permit? A contract with the local power company for the grid intertie? Do the permitting authorities require that work be done by a licensed professional?

Equipment and tools: Do you own or have access to the necessary tools and equipment, some of which may not be a part of the average tool kit?

Installation: Do you have a working knowledge of Article 690 and other articles of the *NEC* necessary to install a safe, code-compliant system? Do you need to hire someone to consult on these issues?

Every site and system is different, as are the possible solutions—the Inouyes' ground mount was built on sloped ground back-filled to near level.

Choosing the Components

In 2007, we significantly reduced our electricity demand by installing a solar hot water system (see "Do-It-Yourself: Tips for Solar Hot Water Success" in *HP123*). The next year, we replaced our smaller wood heater with a larger and more efficient cast-iron one. Our horses drink from a geothermally heated water fountain, rather than a resistance-heated tank, during the winter. A new, homemade solar hot air panel has just started reducing some of our winter cordwood consumption.

Rather than bring in propane, we've kept all of our other energy loads on electricity. Our home is already connected to the grid, so the reduced cost and increased simplicity of a grid-tied PV system was the logical choice. Our electricity bill history showed that the new system would need to produce an average of 680 kWh per month (about 22.4 kWh per day) to cover our electricity needs. Our local average daily insolation is about 4.8 peak sun-hours. According to PVWatts (see Access), offsetting 100% of our electricity consumption would require a 6.5 kW PV system.

PV array interconnects and grounding are among the easier parts of system design and installation.

In the end, we went with a 5.7 kW system which, according to PVWatts, should cover about 87% of our yearly electric usage. This was largely dictated by PV module prices, since the biggest cost in a solar-electric system is the PV array. We were able to find a pallet (28 modules) of "blemished" PV modules (cosmetic problems only, with full functionality, output, and warranty). Additionally, these Evergreen modules have a positive-only (+2.4%) production tolerance, which should increase the yearly energy production to above the PVWatts estimates, since PVWatts assumes a -5% production tolerance.

The next choice was the inverter, which requires careful planning. An array voltage that's too high can damage the inverter, while low voltage or amperage will run the inverter less efficiently, and can cause the inverter to drop out. Inverter sizing calculations must take into account that array voltage output drops in hot weather and is higher in cold weather, and can decrease over the years. (See "Grid-Tied Inverters Buyer's Guide" in *HP133* for tips on selecting an inverter.)

PV module manufacturers supply some of the information you'll need, such as module specifications and how much module output varies with temperature. Some data you'll determine based on your local temperature extremes and mounting system. And other data will come from the inverter manufacturer. Fortunately, most major inverter manufacturers provide online calculators to help you figure out string sizes for their inverters. If you're designing a system, you need to understand all these variables, and you'll want to check the online results with your own calculations—I found that online string calculators gave useful results, similar but not always identical to hand-calculated figures. (For

more information, see “String Theory: PV Array Voltage Calculations” in *HP125*.)

We determined that a single PV Powered PVP4800 inverter would fit our needs. It tolerates lower environmental temperatures (-13°F), so no enclosed or insulated/heated/actively vented space would be needed. On the rare days when the temperature drops below -13°F, the PVP4800 will shut down and then safely resume work after the sun has warmed things up a bit.

In addition to the PV modules and inverter, there are many other components needed, such as disconnect switches, fuses, breakers, wires, lightning arrestors, conduit and a combiner box. Find a component dealer that offers the info you need, and staff willing to help select compatible components. There are other good ones, but we decided on Affordable Solar.

Putting the Pieces Together

If the PV modules are not going to be roof-mounted, you'll still need to decide between a pole mount and a ground mount. Poles allow the use of trackers, and make it easy to adjust for seasonal elevation changes—but the installation complexity and cost goes up accordingly.

A tracked array was not a cost-effective solution for our site. In the late afternoon, the sun disappears behind a hill, cutting back the energy that could be gained by using a tracker, which is easiest to justify when there is horizon-to-horizon solar access. In the end, we decided on a fixed, ground-mount. Compared to an adjustable ground-mounted system, having a fixed ground mount at 45 degrees would only incur a 4% energy loss per year. Plus, a ground mount would not require the specially fabricated and more expensive horizontal pole-top racking system that our deep snows would dictate. It was also something I could build myself and for less than a pole-mounted system.

Siting & Designing the Ground Mount

Next, I needed to look for shading problems in the solar window. The sun-path software offered by the University of Oregon Solar Radiation Monitoring Laboratory told me what the sun's elevation and azimuth would be year-round. I scoped

The author feeds wires into the long conduit run to the utility meter.

out those sun positions using a Suunto KB-14 optical compass and a Suunto PM-5 clinometer, finding that another dozen trees would need to be removed. With our firewood bays well stocked and our vegetable garden less shaded, the result was a solar window of at least six hours per day, year-round.

Once I'd determined the array location, I laid out the ground mount, which involved basic surveying skills and equipment. Our backyard is sloped, and rather than engage in complex math and sloped construction, I leveled the ground. Each post sinks at least 3 feet below the original grade, and all posts benefit from 1 to 4 feet of additional fill above the original grade. In retrospect, having moved some 40 cubic yards of gravel, rock, and dirt for this project, perhaps I should have done the complex math instead.

If you're designing your own ground mount, CAD software can make the job easier. I've used various versions of TurboCAD Deluxe over many years on numerous construction projects, including this one.

I built the ground mount with large treated timbers—a construction method that I'm familiar with after building our

Balance-of-system components, including a basic AC disconnect (far left), which was replaced with a load center and circuit breaker.

To complain or comply—the additional, inspector-required, load center and circuit breaker (far left) on the inverter output.

sheds and pole barn, and I had the needed heavy equipment. Having learned from prior mistakes, I knew to build only on undisturbed ground and to give adequate vertical support to prevent the structure from sinking under snow load. Rebar inserted horizontally through the vertical posts helps secure them inside 2-foot-diameter steel culvert collars filled with 5/8-inch gravel. The timbers are attached together with 1/4-inch steel plates, 6-inch channel iron, and 5/8-inch grade-8 steel bolts. All timbers are diagonally braced with tension wires tightened with 1/2-inch galvanized turnbuckles. Even though the timbers were pressure-treated for long-term ground contact and largely sheltered by the array, all exposed wood was protected with waterproof sealant.

The rack, which secures the PV modules to the timber structure, was home-built using Unistrut. This erector-set-like hardware comes in various sizes and gauges, with assorted connector and fastener options. Structures in this area should be designed for maximum snow loads of 59 pounds per square foot, and Unistrut's P5500 galvanized channel had the load strength to span the horizontal timbers. After cutting each module support channel to length, the leftover pieces were used at the top and bottom of the rack. This creates a stronger lattice, protects the module edges, and provides bracing and lifting points for sliding the modules into place. The racking is bolted to vertical angle-iron that is bolted to the ground-mount beams.

Once the rack was in place, the next step was to install the PV modules. The Evergreen modules have pre-drilled mounting holes at points that can support 60 lbs./ft.^{2} loads. Special precautions were necessary to avoid galvanic reaction between the aluminum module frames and Unistrut's galvanized steel. I used stainless-steel bolts, nuts, and washers, and inserted 1/4-inch-thick shims between the module frames and channels. The drilled shims (made from aluminum and steel) are each double-wrapped in electrical tape, with additional layers applied to both the module frame and the channel.

The DIY ground-mount cost $4,059, less than half the $10,006 quoted by a commercial installer for two steel pipes set in concrete, with commercial pole-mounted racks.

Connecting the System

Next came mounting the 135-pound inverter and other electrical components (combiner box, disconnect switches, meter base, and breaker box) on a plywood panel attached to the timber structure.

With the mechanical work done, it was time to wire everything together. Connecting the PV modules was easy—their pre-wired MC-4 lockable connectors simply snap into each other. The two 14-module series strings come together in a MidNite Solar MNPV6 combiner box, where each is protected by a 20 amp, 600 VDC fuse.

Wiring was complicated by the need to keep voltage drops (line losses) small to minimize energy loss. The modules came with #10 AWG wire, so I also used #10 wire for the short wiring run to the combiner box. The 165-foot underground run (from the inverter location to the home service-disconnect location) needed larger #4 AWG wire to keep the 240 VAC line loss less than the 2% recommended in the PVPowered installation manual. I used #4 wire for the many short connections on either side of the inverter, except for the inverter itself, which would only accept smaller #6 wires. The terminals in the disconnect boxes on either side of the inverter allowed transitioning the #6 inverter wiring to the #4 long run wiring.

PV equipment grounding is important to ensure human safety and to minimize risk of equipment damage from lightning. I grounded my steel racking with heavy-gauge bare copper ground wires (#4 and #6 AWG). The wires are secured to the structure by 15 steel clamps and electrically connected with one lay-in lug, then clamped with acorn nuts to two widely separated 8-foot-long copper-plated grounding electrodes pounded into the earth. An additional run of #6 AWG bare wire goes to every PV module, secured by lay-in lugs. If lightning affects the modules and gets into the DC wiring, it should short to ground through a lightning arrestor. On the AC side of the inverter, two more grounding electrodes and another lightning arrestor are wired in, plus another pair of grounding electrodes at the service disconnect.

Strategies for Success

When your new PV system coming on-line feels like it's just around the corner, it can be frustrating to have everything held up by inspection delays. One mistake I made was assuming that the electrical inspector would be familiar with PV installations. In retrospect, it would have been better to offer him more detailed information up-front. For instance, he wanted documentation (other than the label on the unit) proving that the inverter was UL listed. Then, when he decided to require ground-fault protection, it was up to me to persuade him that the ground-fault indication/detection (GFID) system was built into this inverter at the factory. He also required adding traditional breakers between the inverter AC output and the production meter. This was to protect the long underground wire run, even though it already benefited from three other types of overcurrent protection at this end: two DC

Some utilities require a lockable disconnect at the point of connection with the utility.

Research, skill, patience, and hard work pay off with a quality, code-compliant, and cost-effective PV installation.

string fuses, an inverter that can't produce more than 21 amps AC, and panel strings that max out at 9.2 kW. Sometimes it's easiest to just add whatever components the inspector wants, rather than debate the finer points of the *NEC*.

I ran into similar glitches with our local power company for the grid interconnection. Their unfamiliarity with PV systems resulted in some uncertainties and difficulties at the management level. To this day, Pacific Power's computer still has trouble digesting our meter data, which delays each monthly statement. In contrast, their front-line employee, who installed the net and production meters, helpfully answered questions, responding promptly. My hope is that both the inspection and grid-tie steps will become easier for others once this technology becomes better understood in our region.

Do the Homework

This DIY project involved many steps and technologies that I hadn't used before. All the parts had to be researched and ordered ahead of time, with each major component having implications for the others. Tackling a solar-electric installation isn't impossible, but it does require that you be comfortable taking on the duties of the overall project manager, plus responsibility for making each minor step work.

The skills and experiences you start out with will determine what additional knowledge you need for a successful installation. For me, it meant lots of reading; the two most helpful books were *The New Solar Electric Home* by Joel Davidson and Fran Orner, and *Got Sun? Go Solar* by Rex Ewing and Doug Pratt. Article 690 of the *NEC* is mandatory reading (an expensive publication to purchase, but available for free at our public library). It's rather dry, so help yourself by also reading the commentary in one of the *NEC* handbooks (I bought the McGraw-Hill version). When those resources left me with specific PV questions, John Wiles was kind enough to answer several e-mails. The manager at our local electrical supply house was very patient in suggesting practical solutions for some of the wiring issues that came up during installation—he was interested in the PV system and repeatedly offered advice and helped with problem solving.

Beyond hands-on knowledge, flexibility is also important to a PV project. Because it's not a one-size-fits-all situation, you'll need to adapt the system to site specifics including available space, shading, and energy needs. Keeping that same flexible attitude when using ground mounts and racking may also open up opportunities for savings. I used www.craigslist.org to locate many used items at attractive prices, including 40 feet of 24-inch-diameter culvert, 20 feet of 6-inch channel iron, creosoted railroad ties, 2-inch angle iron, and a sack of galvanized turnbuckles. Craigslist also turned up some of the tools I used for this project, including a tall orchard ladder and a band saw.

Part of a successful DIY project is knowing your limits, and calling for help as needed. Some of the heavy lifting was beyond my capacity, so I was grateful for help with setting the largest timbers. Some of the high-voltage wiring and dealing with electrical inspectors was beyond my experience, so I consulted with an electrician before undertaking these tasks.

In the end, after five months of planning and building, it was exhilarating to do the final circuit testing and then apply power to the inverter, a true "we have liftoff" moment. In the 109 days since we commissioned the system, the summer's average daily production of 28.2 kWh has exceeded our average daily use of 17.9 kWh, leaving a surplus of 10.2 kWh per day to draw on during the darker winter months. By the winter solstice, we'll have six months of data, and a pretty good idea of what portion the PV system will provide of our overall needs. Meanwhile, our heightened awareness

DIY PV System Costs

Item	Cost
28 Evergreen PV modules (blems)	$18,514
PVPowered inverter	2,895
Misc. electrical	2,772
PV support, homemade	2,437
PV rack, homemade	1,554
Travel expense (to pick up parts, equipment)	861
Books	132
Total	$29,165
Less 30% Tax Credit	$8,750
Grand Total	$20,415

of our electricity use has already resulted in reducing our consumption. We're using our two solar ovens more, timing clothes washing to synchronize with peak solar water-heating, adding power strips to turn off rarely used electronics, updating our computer's old CRT monitor to a more efficient LCD monitor, and using more efficient irrigation practices to reduce pump run-time.

Will this PV project prove cost effective? I think so. The total up-front cost came to almost $30,000. We will be receiving the 30% federal income tax credit, the Washington State production payments of 15 cents per kWh, any future green tag payments (presently unavailable here), and the savings on our power bills. Over time, we'll get updated energy production figures for this system, and we'll see what increases in grid energy rates we are avoiding. To date, data predict a 14-year payback for a system that should last twice that long. The clear environmental benefits were enough to draw us into this project, but it will probably also save us money over the next two to four decades. We're even considering doubling the system, which could provide enough additional energy for an electric car.

Access

Bob Inouye (email@inouye.us) lives with his wife Carol in the foothills of the Cascade Mountains in Washington. The couple happily shares 180 forested acres with horses, mule deer, elk, turkeys, beaver, salmon, and steelhead.

PV System Components:

Evergreen Solar • www.evergreensolar.com • PV modules

PVPowered • www.pvpowered.com • Inverter

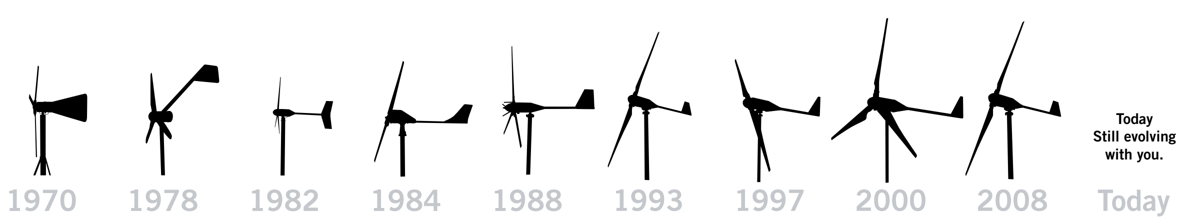
Affordable Solar • www.affordable-solar.com • PV system components

Other Resources:

Power Trip Energy • www.powertripenergy.com • PV seminar

University of Oregon Solar Radiation Monitoring Laboratory • http://solardat.uoregon.edu/SoftwareTools.html • Free sun-path calculation software

PVWatts • http://rredc.nrel.gov/solar/codes_algs/PVWATTS/version1/ • PV system production estimates



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INVERTER *basics*

The best type of inverter for your application is the one that meets the system's requirements and results in the highest performance for the lowest cost, while operating reliably. Here's how to make the best match.

by Christopher Freitas

Renewable energy system designers and installers often say that the inverter is the brains of an RE system. But I've always thought of it more as the system's stomach: It digests the energy provided by the PV modules or batteries into something that is more useful and better regulated.

The main function of an inverter is to convert direct current (DC) into alternating current (AC), and to change the voltage level into a stable 120 or 240 VAC that can be used by household appliances or "sold back" to the utility grid.

The word "inverter" was originally used because the output wave form produced by its circuits alternates between a positive and a negative voltage. This device "inverts" the polarity of the power source (typically, a battery or PV array), causing the current to flow in alternating directions through the load. Hence the term "alternating current."

Inverters have a wide variety of designs, capabilities, and features. Understanding their differences can be as simple as dividing them into two groups based on their cost.

Inexpensive Battery-Based Inverters

Low-priced inverters (less than $500) are available from auto parts and large retail stores, as well as the Internet. The smaller ones (less than 400 watts) plug into an automobile's cigarette lighter jack, while the larger ones (500 to 3,000 W) require a connection wired to a battery. (For safety reasons, this connection should be fused, but often this is not mentioned in the sparse instructions provided.) These inverters usually have very few safety or protection systems and are not listed to any UL standard. Usually, only short-term warranties apply and no customer support is available.

Low-cost inverters are for small electronic loads, such as small TVs and laptop computers. Although some of the higher-power models can power hand tools, the quality of the output power while the tool is operating may damage other more sensitive loads that are also connected. Some AC loads, such as some chargers for rechargeable battery packs, as well as the batteries themselves, can be damaged by the poor AC output wave form and poor voltage regulation, since they do not produce a true sine wave output (see "AC Output Wave Forms" sidebar for more information).

Most inexpensive inverters lack isolation between the DC input and the AC output. Typically, the DC negative is directly connected to the AC neutral. This allows them to be smaller, lighter, and cheaper to manufacture. This can, however, be a hazard when trying to install them in a *National Electrical Code*-compliant manner or if used with ground-fault circuit interrupter (GFCI)-protected AC outlet circuits.

Inexpensive inverters should not be used for residential or commercial systems, which need to meet the requirements of the *NEC* and/or be inspected. These inverters also cannot be grid-tied as they do not include the necessary synchronization capability or the protection systems required by utilities to protect utility line-workers and homes. Their limited safety systems also mean that they should only be used with continuous supervision, in case a problem with the inverter or a load occurs.

Exeltech's XP line provides a super-clean wave form appropriate for sensitive electronics.

Courtesy www.exeltech.com

Many inexpensive inverters boast power ratings that are not based on a continuous operation or real-world conditions. These power ratings may make some appear to be a better deal, but disappointing performance often occurs. To ensure acceptable operation and reliability, choose one with a power rating twice as large as your application requires. The low efficiency (often less than 80%) of most of the cheaper inverters can result in lower overall system performance—requiring additional, expensive PV modules—resulting in higher overall system costs.

Expensive Inverters

More expensive inverters (more than $1,000) are designed to operate in an efficient and safe manner continuously, even under less-than-ideal conditions. These inverters are designed for permanent installation and are compliant with both *NEC* and UL requirements. Because they include more protective and safety systems, they are larger and heavier than inexpensive inverters. They are well worth the extra cost when the application requires an efficient, reliable, and safe source of AC power.

Expensive inverters almost always include DC-to-AC isolation, which meets *NEC* and UL requirements and allows them to be used with GFCI circuits safely. They are also nearly all listed to one of the UL standards—either UL 1741 (for residential and commercial RE systems) or UL 458 (for RV and boat systems). Standards testing may be done by one of several nationally recognized testing laboratories such as UL, ETL, CSA, or TUV.

Expensive battery-based inverters often include additional features and capabilities, such as battery chargers, AC transfer switches, metering, load and generator control outputs, and even data logging and networking connectivity. Not all expensive inverters are the same—some produce smoother AC output wave forms, which makes them more suitable for powering sensitive loads such as electronics (TVs, computers, laser printers, etc.). Review the specifications carefully before selecting and purchasing one. Fortunately, the manufacturers of expensive inverters typically provide good user and installation manuals, as well as customer support and longer warranties.

Terminology

The term "inverter" is often confused with the word "converter," which is a more general term for a device that changes AC to DC (such as a battery charger), or a device that converts one DC voltage into another (DC-to-DC converter), allowing, for example, 12 VDC loads to operate on a 48 VDC battery system. Some modern inverters include both an inverter and a battery charger. Some even have 12 VDC output for operating relays or other devices—it's easy to see why people might be confused by the terminology.

OutBack's FX series is one of several inverter brands used for remote, battery-based applications.

Different Inverters for Different Applications

High-performance inverters are optimized for specific applications—there is no universal "one-size-fits-all" inverter. The range of inverter applications can be divided up into four categories:

- Off-grid
- Mobile
- Grid-tied with battery backup
- Batteryless grid-tied

It is important that the inverter you select is designed for the application for which it is being used. Otherwise, poor reliability and performance may occur and unsafe situations may result, which could damage the inverter or endanger the system's users or utility workers.

OFF-GRID. All off-grid inverters work with a battery bank that provides power, even when it is not sunny or windy. These inverters are typically able to work with multiple sources of power—solar, wind, hydro, and engine-generators—even at the same time.

AC wave form. Off-grid inverters are available with a variety of AC output wave forms. Today, most home and commercial power systems use sine wave inverters for sensitive loads. Many of the smaller systems (for cabins or other locations that do not have sensitive loads) still use modified square wave inverters since the cost is lower.

(continued on page 92)

AC OUTPUT WAVE FORMS

Lower-cost inverters produce a simpler square wave instead of the more complex sine wave. Some sine wave inverters have very visible, coarse steps making up the sine wave, while others have very smooth waves, by using hundreds of steps and more sophisticated AC output filtering.

The AC output wave form is also affected by the load being operated and the DC input voltage level. Many lower-cost inverters cannot regulate the AC output voltage when running more difficult loads such as motors, which can result in voltage spikes that may damage some appliances. More expensive sine wave inverters can operate nearly any load without problems and often have better power quality than a utility grid, since the utility distribution system can be affected by other AC loads operating in your neighborhood, resulting in power-quality issues.

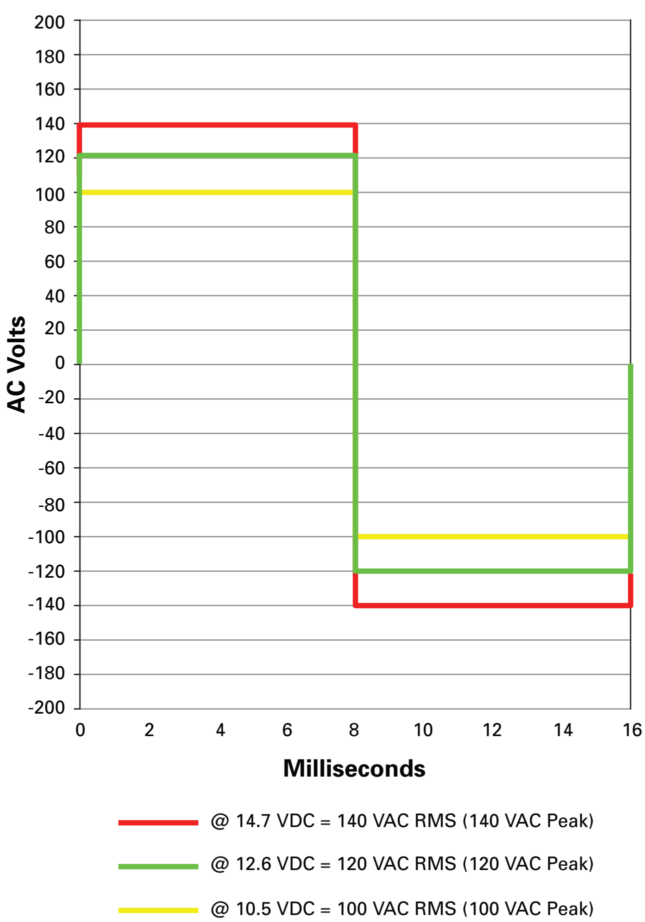
Square Wave Inverters. The easiest AC output wave form to make is a "square wave," in which the voltage alternates from positive 120 volts to negative 120 V, back and forth. This wave form has a lot of total harmonic distortion (THD) and results in poor operation of nearly all AC loads.

A square wave inverter cannot regulate its AC output voltage when the battery voltage changes significantly. They produce 120 VAC when the battery is at 12 VDC, but also produce 140 VAC when the battery is at 14 VDC and 100 VDC when the battery voltage is pulled down to 10 VDC, like during a motor startup. This can cause even simple AC loads like motors or lightbulbs to fail prematurely.

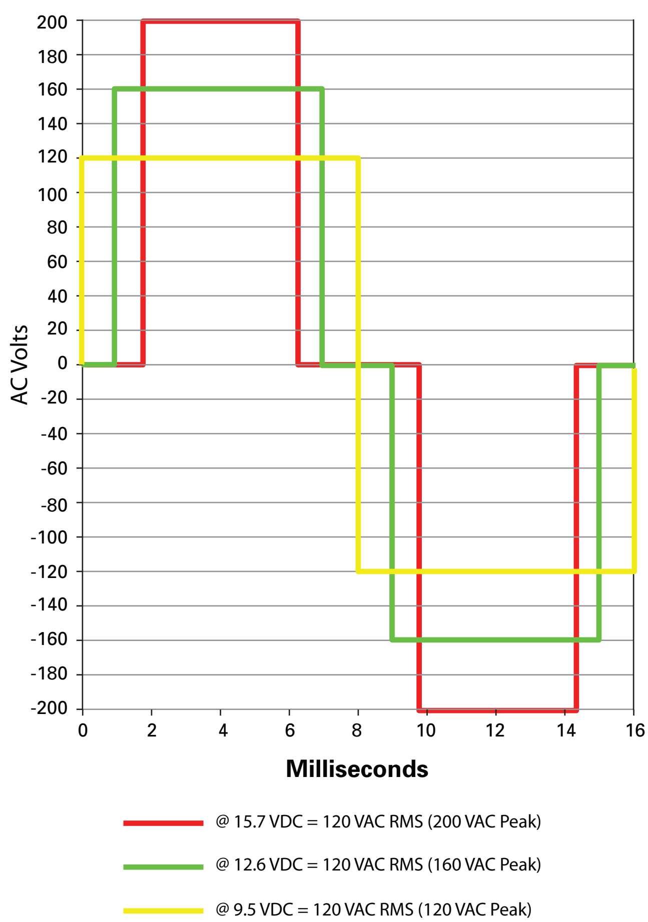
Because of these severe drawbacks, no square wave inverters are being manufactured today. They still do sometimes turn up used, but they are not worth considering, even if they are free.

Modified Square Wave Inverters. The addition of a small "off" time between the positive and negative pulse of the square wave significantly reduces the THD. And the shape of the wave form also can be controlled to allow regulation of the AC output voltage level as the battery's voltage changes. Modified-square pulses are tall and narrow when the battery voltage is high, but become short and wide when the battery voltage is low. This results in a consistent average voltage being supplied to the AC loads, and improves load

Square Wave Inverter AC Voltage at Low, Normal, and High DC Input Voltages



Modified Square Wave/Modified Sine Wave Inverter AC Voltage at Low, Normal, and High DC Input Voltages



compatibility and performance. However, more sensitive loads, such as variable speed motors on some hand tools and appliances, may still operate incorrectly, overheat, and be damaged from this type of wave form.

All of the inexpensive inverters and even some of the more expensive off-grid and mobile inverters produce this type of AC wave form. This wave form cannot be used for grid-tied inverters as the THD does not meet the utility requirements.

Modified Sine Wave Inverters. Although this term is commonly used, it is really a misnomer—there is no difference between a modified sine wave inverter and a modified square wave inverter, other than some sleight-of-hand marketing.

A **stepped sine wave inverter** produces another "in between" AC wave form. Instead of having a single positive or negative pulse punctuated by an "off" period between, a stepped sine wave inverter is able to produce a series of different voltage levels which can be arranged to produce what is often described as a "Mayan temple" shape. The number of steps varies as the battery voltage changes. At higher battery voltages, there are fewer, but taller steps; at lower battery voltages, there are many shorter steps.

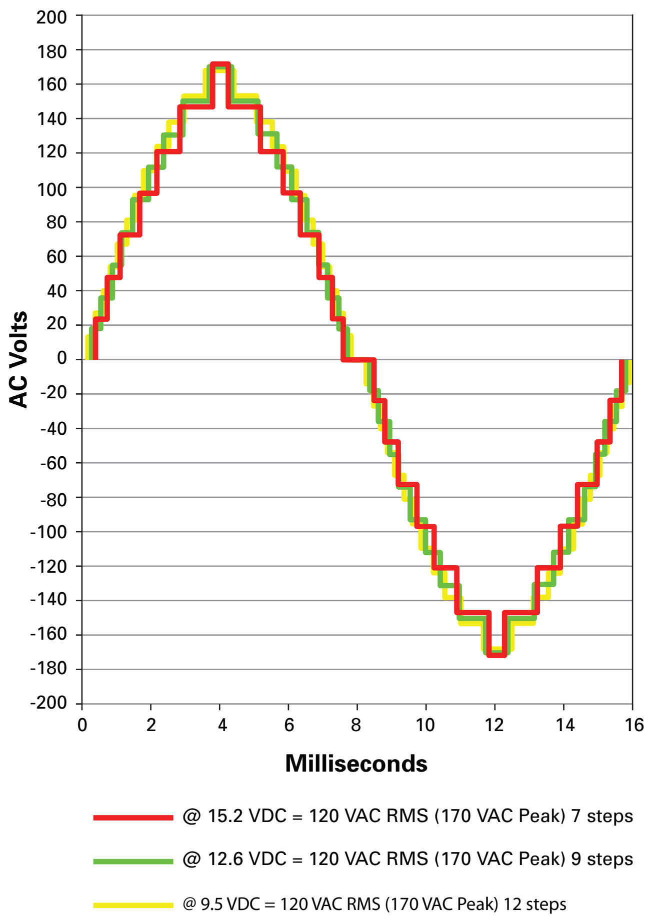
This approach produces a wave form with a much lower THD than a modified square wave inverter and offers good performance and DC-to-AC conversion efficiencies of more than 90%. Some of these inverters are even able to be grid-tied since the THD is low enough to meet UL and utility requirements.

True sine wave inverters produce a wave form that closely matches what is provided by a utility grid. Some of them are able to provide AC power that is better regulated and even has lower THD than utility power.

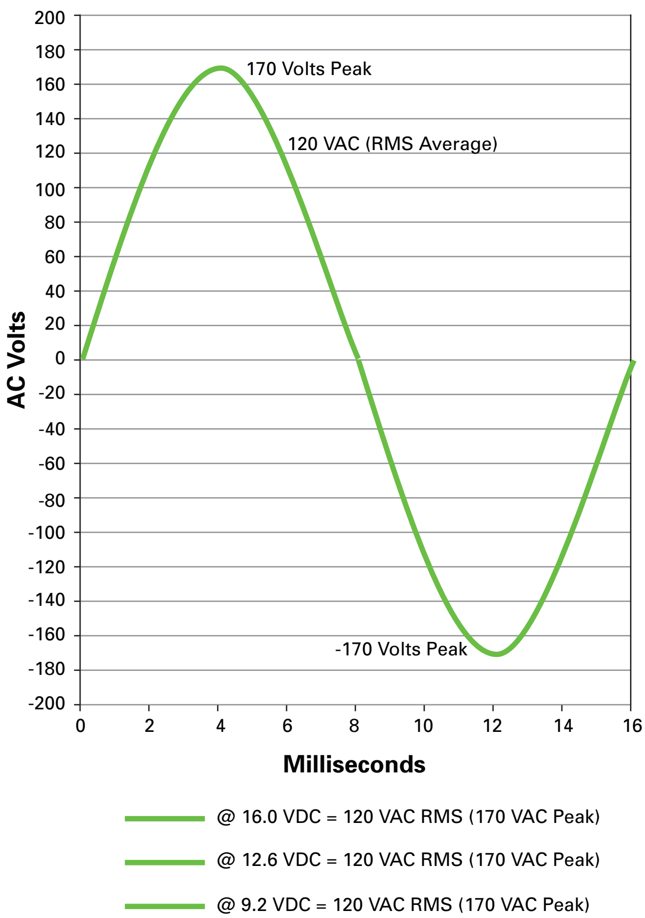
To make this wave form, a true sine wave inverter produces hundreds of positive and negative pulses during each AC cycle. These pulses are then filtered into a smooth sine wave shape. Most true sine wave inverters are able to adjust the duration and timing of each pulse by using very fast digital electronic circuits and/or microprocessor control. This allows the voltage and frequency to be well controlled, ensuring that any AC load within the inverter's power limits will operate properly.

Because the output is a well controlled, very sinusoidal shape, using these inverters for grid-tied applications is possible by the addition of the required safety systems and the additional testing and certification to meet the requirements of UL1741 and utilities.

Stepped Sine Wave Inverter AC Voltage at Low, Normal, and High DC Input Voltages



Pure Sine Wave Inverter AC Voltage at Low, Normal, and High DC Input Voltages



Power rating. Because an off-grid inverter usually has to provide all the power required by the AC loads, its power rating is a critical factor. Fortunately, off-grid inverters include detailed information describing their continuous power as well as short-term "surge" capabilities.

Surge power. The inverter's surge power rating is its ability to provide high power levels for short periods of time (seconds) when certain loads—typically, AC motors, such as well pumps or power tools—are started.

Conversion efficiency. This is how much of the power consumed by the inverter is actually available to power the AC loads. Inverter efficiency can range from 70% to up to 96%. The actual performance depends on the amount of AC loads being powered and the type of wave form provided. Efficiency is typically the worst at very low power levels (less than 100 W) and best at about 25% to 50% of the inverter's continuous power rating.

Idle power consumption. Although the efficiency of an off-grid inverter is very important, be sure to also consider how much power the inverter uses when no loads are being powered—called the idle or tare power consumption. For example, one model may consume 10 W, while another similar inverter might consume 50 W. In just one day, that's a difference of almost 1 kilowatt-hour being consumed (40 W x 24 hours = 960 Wh). Some off-grid inverters use a search mode to reduce energy consumption, turning off all but the search capability when no load is present. Although this is useful in some applications, many homes have AC loads that require power continuously—such as security systems or answering machines—negating any potential energy savings from search mode.

The Xantrex XW series is designed for off-grid as well as grid-intertie systems with battery backup, which is useful in the event of grid failure.

While Magnum also makes residential RE system inverters, its ME series is designed specifically for mobile applications.

Battery voltage. Most off-grid inverters work with nominal battery voltages from 12 to 48 VDC, with the surge power and conversion efficiency being the best on the 24 and 48 VDC inverters. A few larger inverters (more than 10 kW) are designed to work with even higher voltage batteries—up to 240 VDC—but this requires specialized installation, safety procedures, and even different battery construction. Generally, the benefit of using a battery bank with a higher voltage than 48 VDC is not advantageous compared to the possible hazards it adds, unless the system size is very large (more than 30 kW).

Options. Many off-grid inverters are available with a built-in battery charger and AC transfer switch. This allows connection of a backup source (like the grid or an AC generator) to charge the battery and/or run AC loads when battery power is insufficient. It's a good idea to include this feature even if the application does not have a generator, since this will allow easy future load expansion or periodic battery equalization charging by simply connecting to an AC source, even if only occasionally.

MOBILE. Most mobile inverters are similar to off-grid inverters. Although most are 12 VDC, some 24 VDC systems are used on larger motor coaches and boats, and in military applications. Special mobile inverters are even designed to handle severe vibration conditions or even corrosive environments, such as saltwater spray or alkaline dust. Knowing the requirements of the application is critical to selecting an inverter that will not only operate the loads acceptably, but also work reliably.

GRID-TIED WITH BATTERY BACKUP. A few models are available that can "sell" power back to a utility grid when the battery is full. Having a battery backup system adds considerable complexity to a grid-tied system, but it can be a useful feature for those with frequent or lengthy utility outages or who want to be well prepared for possible natural disasters or emergencies. Be sure that the inverter documentation clearly states that it is designed for grid-tied operation and that it is has been tested and approved to the UL1741 standard for grid-interactivity.

Backup AC load panel. A battery backup system typically requires a separate AC load panel for the circuits that will continue to operate when a utility outage occurs. Installing these panels—and wiring the individual circuits to them—can be time-consuming.

Batteries. Batteries are best placed in a protected location to keep them warmer in the winter and cooler in the summer, and out of reach of children and pets. Be prepared to replace the batteries every three to 12 years depending on their charging regime, usage, capacity, and battery type.

Courtesy www.sma-america.com

Using AC coupling, the SMA Sunny Island inverter can be used in off-grid and battery backup grid-tied systems, as well as to build minigrid village power systems.

Neutral/ground switching system. The primary difference between a mobile and an off-grid inverter is how the AC transfer switch works. Mobile inverters include additional switching circuits that disconnect the AC input neutral and make a connection between the AC output neutral to the ground conductor when operating in the inverting mode. This prevents a ground fault from occurring when the RV or boat is plugged into a pedestal or shore power. A ground fault can result in shock or electrocution.

Efficiency. In most mobile applications, the engine of the vehicle does most of the battery charging so the inverter's efficiency may not be as critical as with off-grid applications. However, if you spend extended periods of time "boondocking" or parked without running the engine or being connected to the grid, then careful attention to selecting an inverter with the highest conversion efficiency and the lowest idle power consumption is important. The higher performance and longer battery life will be worth the extra money.

AC input capacity. It is important not to pull more AC current through the inverter's AC transfer switch than it is capable of handling. Be sure to follow the manufacturer's instructions and install proper overcurrent protection to prevent damage if an overload occurs.

AC wave form. Although many RVs use modified square wave inverters, many RVs also have sophisticated electronics and sensitive loads, which won't run as well on this type of wave form. Choose a sine wave inverter for compatibility.

Some inverters, like this Aurora PVI series made by Power One, are designed for highly efficient batteryless grid-tied applications.

Courtesy www.power-one.com

Efficiency and costs. Backup capability to a grid-tied PV system does come at a cost—the conversion efficiency will be about 5% less than for a batteryless system, and the system cost can be as much as 25% to 50% more due to the additional controllers, batteries, other balance-of-system requirements (combiner boxes; battery cables and enclosures; inverter accessories; critical loads subpanel; etc.) and increased installation time.

BATTERYLESS GRID-TIED. A batteryless grid-tied inverter is designed to do one thing very well—power AC loads from an RE system along with the utility grid and "sell" any surplus energy back to the utility. Because these inverters do not require batteries, the system and installation cost is lower and the efficiency is usually higher. The downside is that the system is unable to provide AC power during a utility power outage even though the sun may be shining or the wind blowing.

Input voltage window range. Most grid-tied inverters are designed to work with a specific PV array configuration or a particular wind turbine. The input voltage of most batteryless grid-tied inverters is very high—many can accept up to 600 VDC and require at least 200 VDC to start operating. However, it is critical that the PV array operate within the inverter's voltage window or damage and/or poor performance may occur.

Tested and certified. To sell power to a utility, a grid-tied inverter has to produce a very accurate sine wave AC output with very low total harmonic distortion (see "AC Output Wave Forms" sidebar) and must be tested and certified to meet safety and performance requirements to protect the utility's infrastructure and personnel. All batteryless grid-tied inverters should be factory-labeled stating that it is designed for grid-tied operation and has been tested and approved to the UL 1741 standard. (For more information on batteryless grid-tied inverters, see "Grid-Tied Inverter Buyer's Guide" in *HP133*.)

Access

Christopher Freitas (cfreitas@sunepi.org) has worked in the PV industry since 1986 as an electrical engineer. He has participated in the development of many UL, *NEC* and IEEE standards, and volunteers on developing-world RE projects with Sun Energy Power International. He lives in an off-grid solar and microhydro-powered home in Washington state.

Pump Stations

by Brian Mehalic

Pump stations can offer cost and time savings for installers and homeowners alike.

While these two SHW systems have different features, the system with the pump station (right) is more compact and easier to navigate for servicing.

Courtesy Chuck Marken

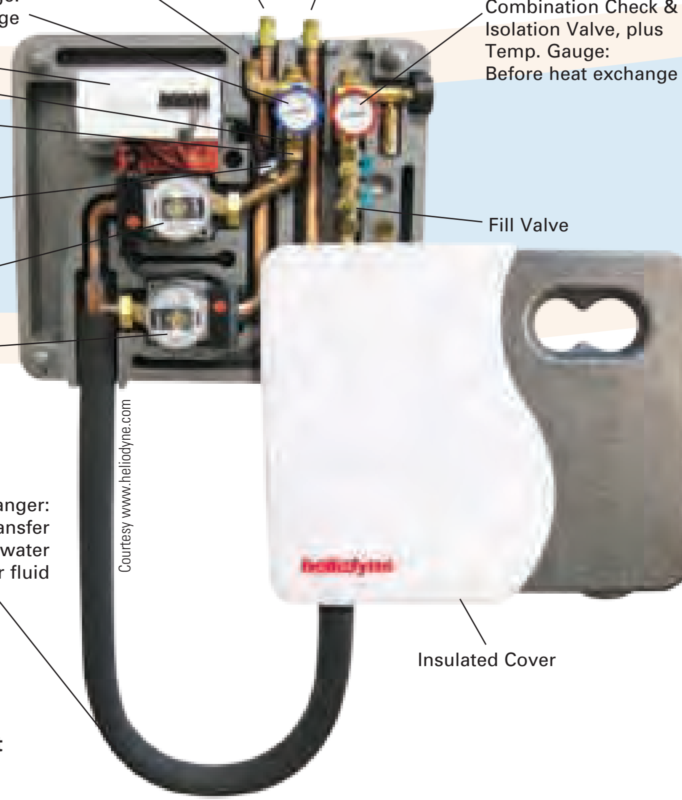
Courtesy Brian Mehalic

Pump stations are available in numerous configurations and designs, and from a variety of manufacturers. Companies specializing in SHW components frequently sell pump stations—either of their own design or rebranded models from independent manufacturers. These "kits" are also available from radiant floor companies and general plumbing companies. In many cases, pump stations are available in packages with tanks designed for direct mounting, or they can be used with other tanks from different manufacturers.

System Suitability

Most pump stations are for use in closed-loop, active solar hot water systems—the dominant domestic system type. A heat transfer fluid (HTF) is circulated through a collector and then transfers the heat to the domestic, potable water in a storage tank. There are many variations, the most common being pressurized systems, which use a freeze-resistant fluid such as propylene glycol, and drainback systems, which are unpressurized and often use water as the HTF.

Pump Station with Integrated Heat Exchanger



Courtesy www.heliodyne.com

The Helio-Pak by Heliodyne has two pumps and uses a tube-in-a-tube heat exchanger.

In addition to the components typical of pump stations, the Purist SPS-2-AC features a stainless-steel plate heat exchanger, two pumps, an integrated controller, and data monitoring via a personal computer.

Courtesy www.puristenergy.com (2)

However, most pump stations have pumps that are too small to overcome the increased head typical of many drainback systems, so are best suited for pressurized, closed-loop systems. Depending on the model and system layout, it may be possible to replace the pump with a larger size or plumb a second pump in series to overcome the head and achieve the necessary flow in a drainback system. (Caution: Using two pumps in series can have serious consequences—if one pump fails, the other pump may be able to move fluid only high enough to allow it to freeze in the tubing.)

With or Without a Heat Exchanger?

A primary distinction between pump stations is if they include an integrated heat exchanger, which is required for closed-loop systems. There are three potential locations for the exchanger: it can be built into the storage tank; it can be an independent component plumbed into the system; or it can come preassembled as part of the pump station.

Models such as the Taco Solar Pump Station, Heliodyne HPAK, PAW Solex, or Purist SPS-2-AC can be used with standard or four-port hot water tanks because the heat exchanger is built into the pump station. These types of tanks are less expensive than tanks with built-in heat exchangers and may be more readily available (see "Solar Hot Water Storage" in *HP131* for more information on tanks with built-in heat exchangers).

The Taco Solar Pump Station has an integrated stainless-steel plate heat exchanger, controller, and mounting bracket.

Pump stations that include built-in heat exchangers have two pumps, one to circulate the HTF and the other to circulate the domestic water through the exchanger. These stations will have four connections: HTF in (from the collector) and out (to the collector); and domestic water in (cold) and out (heated). The size of the heat exchanger must be adequate for the system size, and models are available that can handle 300 square feet or more of collector surface area. Plate and tube-in-a-tube exchangers are most common (see "Fundamentals of Solar Heat Exchangers" in *HP128* for more information). Different sizes of heat exchangers may be available in the same pump station.

Pump stations without heat exchangers are less expensive, but require a tank with a built-in exchanger or a separate, external exchanger, both of which add cost. Overall, a pump station with an integrated heat exchanger paired with a four-port tank will be less expensive then a pump station and a tank with a built-in exchanger. However, the price difference is usually not tremendous, so choice depends more on space constraints, availability, and backup heat sources.

Choices of pump stations without heat exchangers include numerous FlowCon models from PAW, some of which are rebranded and sold by other companies. Other manufacturers include companies such as Resol and Solarnetix. Solar thermal component manufacturers such as Stiebel Eltron, Buderus (Logasol), and Schuco (Solar Station) also offer models to complement their internal heat-exchanger tanks, all of which can also be used in conjunction with different brands of tanks or with separate, external heat exchangers.

Many of these pump stations also have four connections: HTF in (from the collector); HTF out (to the heat exchanger); heat-exchanger return (to the pump station); and HTF out (to the collector). The smallest pump stations, however, are only designed with two connections and are plumbed between the heat-exchanger return and the collector. Optional components for these pump stations include isolation valves and temperature gauges, which are installed between the collector's return and the heat exchanger's input.

Applications

Pump stations can be used in a range of applications. The most common is with a single tank, typical of residential SHW systems. While the pump station replaces the components required for basic systems, integrating a second storage tank, external back-up heat source, or space/radiant heating is nearly the same in terms of parts and labor as with a system built from scratch, and depends on the tank and other system components. Particular attention should be paid to pump station selection when installing more complicated systems—many offer preplumbed options for additional storage tanks and backup heat sources, as well as the types of controllers needed.

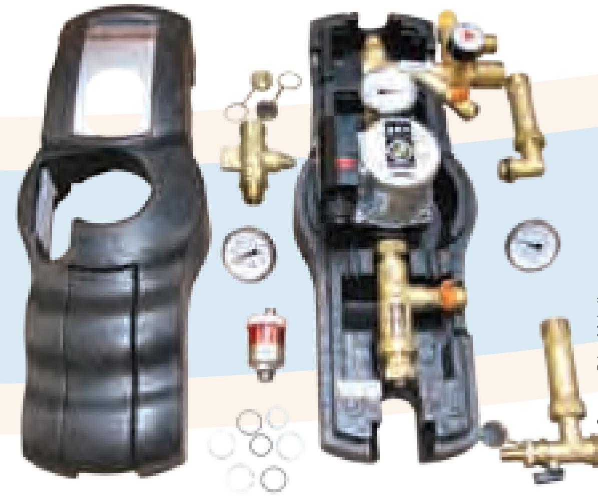
Some models, such as the PAW FlowCon D2F, are designed to operate two independent arrays of collectors so that different orientations can be used to heat the same system. For example, an east-facing collector favoring morning production could be combined with a west-facing collector that heats water primarily in the afternoon. Rather than requiring the HTF to flow through both collectors—one of which would be cooler than the other—two independently operated pumps allow fluid to pass only through a hot array. This could also be accomplished by plumbing two pump stations in parallel on the return from the heat exchanger, and also requires a controller with additional sensor inputs and at least two separately controlled electrical outputs for two pumps.

This Taco pump station does not have an integrated heat exchanger and can be used with an external heat exchanger or tanks with built-in exchangers.

Courtesy Brian Mehalic

Left: In a traditionally built pump stack, these components are assembled and insulated by hand—on site or in advance—by the installer, a very labor-intensive undertaking.

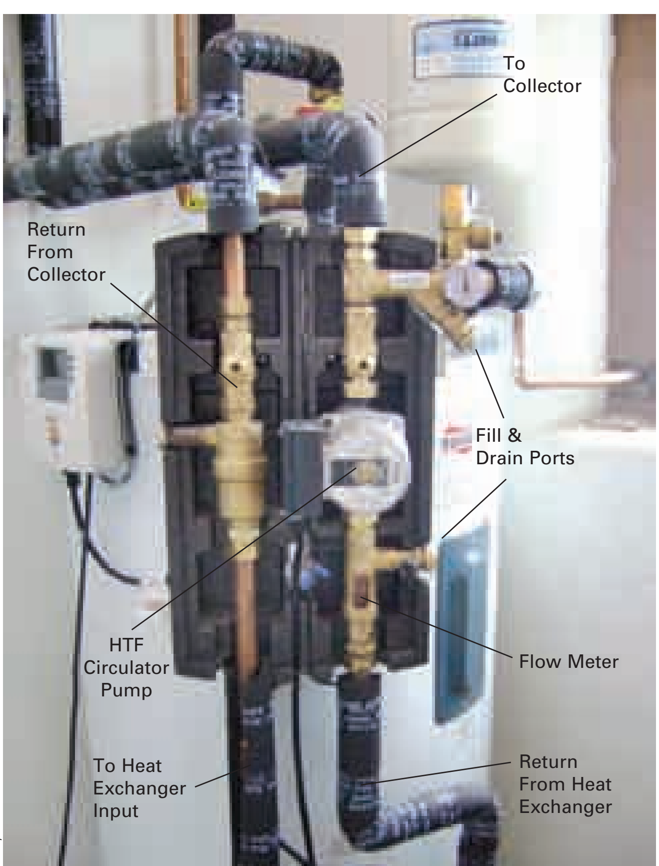
Pump stations offer a neater, less time-consuming installation, though at a higher price compared to assembling individual components.



Courtesy Brian Mehalic

Paralleling two pump stations on the HTF in (return from collector) connections allows two tanks to be heated by the same array of collectors. Depending on the system controls, one tank may be prioritized or both loops may circulate simultaneously as needed, providing heat to both tanks from a single array. Again, the controller must be capable of operating two pumps and reading the temperature of two tanks. The PAW FlowCon S2F is a prepackaged, all-in-one pump station for this type of system. This design can be especially useful for large systems that are prone to summertime overheating. Storage capacity is increased with a secondary tank, which decreases the likelihood of overheating. However the system will heat the primary tank first—and reheat it as necessary—before putting heat into the second tank, which is important for reaching useful water temperatures during the winter when daily peak sun-hours decline.

An installed pump station for a closed-loop system, with components exposed.



Courtesy Brian Mehalic

Features & Components

Many pump stations are made of similar, high-quality components, including brass and copper fittings, and pumps and controllers from well-known, reputable manufacturers. Selecting between the various options often comes down to the specifics of the system design, price, availability, and/or whether the pump station will be mated with a tank from the same manufacturer.

Pump. Pump brands and sizes vary, but most are interchangeable with other common brands. Multispeed pumps are common, providing the ability to adjust the flow rate to the heat available. DC pumps are unlikely to be an option. Typically there will be isolation valves on either side of a pump for servicing or replacing.

Differential controller. Some pump stations include differential controllers, or they are optional, allowing installers to use a favorite model instead. Included controllers may be proprietary or third-party models, and, depending on the unit, may allow for additional sensor inputs and increased functionality for multiple tank or radiant systems. One of two types of sensors, either 10K thermistors (common in U.S.-made controllers) or PT1000 sensors (typical of European controllers), are used for sensing tank and collector temperatures. If the station is added to an existing system, the existing sensors may need to be replaced to ensure compatibility.

Controller choices and features have grown along with the rest of the industry. Many now include advanced displays and system monitoring of collector, bottom-of-tank, and upper-tank temperatures so a user can monitor

Pump Station Tips

A pump station is really a subset of the overall hot water system. As a result, its efficiency and performance is dictated more by system design and installation, rather than by the brand or specs of the pump station. Nonetheless, some of the key features to pay close attention to are:

- **Pump**—What is the brand and type of material? Will it be easy to service/replace, and is it compatible with other pump brands?
- **Controller**—What is the brand and number of sensor inputs and outputs? Is there a display and is data logging available if desired?
- **Station components**—Should be high-quality brass and properly assembled.
- **Extras**—What features or options, such as fittings to connect expansion tanks and brackets for mounting on the storage tank or wall, are available?
- **Reliability**—Are all the parts are in the box and does the system hold pressure?

system operation. Other features may include estimated energy production in Btu; HTF flow rate; and data logging. A desirable feature can run the pump at night to cool an overheated tank, such as could occur during a summer vacation or when hot water is not being used.

Valves and gauges. A pump station includes the valves and gauges required for a pressurized, closed-loop system. Fill and drain ports allow flushing, pressure testing, and charging the HTF loop.

A check valve prevents thermosiphon by allowing the HTF to flow only in one direction. Without it, dense, cool HTF in the collector will sink, causing the HTF to flow in reverse and dump heat from the tank into the collector, cooling the system.

An integrated pressure-relief valve ensures that the HTF pressure doesn't exceed a set limit, and protects the piping and components from extreme overheating or loss of circulation.

A pressure gauge provides a visual indication of system pressure, and if it reads zero or is dramatically below normal system pressure this may indicate a loss of HTF, whether due to a leak or because the pressure-relief valve has operated.

Temperature gauges on the pump station show the HTF temperature before it flows into the heat exchanger and then after it exits, to verify that heat transfer is occurring. Some pump stations are designed to be plumbed between the heat exchanger return and the collector only; in this case, a second temperature gauge would need to be added between the return from collector line and the heat exchanger input.

Other components may include a port and fittings to connect an expansion tank for the HTF, an air separator to remove microbubbles in the HTF, and a flow-rate meter. A valve to regulate flow may also be included, though on some models flow is set with other valves in the station.

The majority of pump stations package all of these components into a streamlined, insulated case, while still allowing access and pump ventilation. Heat is kept in the system and the difficult job of neatly and effectively field-insulating these components is already taken care of.

Limitations & Installation Issues

There is some variability in the specified operating parameters of different pump stations. Be sure to check the specifications for the maximum HTF temperature and pressure. Knowing the maximum HTF flow rate is also important, especially for larger, multicollector systems or if a drainback system (and larger or second pump) is being considered. If the station has an integrated heat exchanger, it must be appropriately sized for the amount of collector surface area.

The size and type of fittings also vary. Many of the popular pump stations are imported, and use metric components. Adapters to standard pipe sizes are included or available, but finding extras locally can be difficult. Whether the station components are metric or not, the adapters are usually easy-to-connect unions or compression fittings.

By themselves, pump stations are not very large—many are smaller than a carry-on suitcase. Weight is not usually an issue, though the stations should be secured, not merely be supported by pipes. Some systems include brackets for mounting on a wall or the tank, or brackets can be easily fabricated. Wall mounts generally require longer pipe runs to the tank, but also may make future tank removal or replacement easier.

Charging the pump station with HTF may require special fittings or a kit, which can then be reused. Some pump stations incorporate a check valve in the pump inlet housing; this is unacceptable for drainback systems and can make filling or charging pressurized, antifreeze systems difficult, so be sure to read the manufacturer's instructions thoroughly. Access to the charging ports is an important consideration for whether to mount the station on the wall or tank. Additionally, when using a pump station and a tank with an integrated heat exchanger, it is a good idea to install a drain valve at the low point where the HTF exits the exchanger, which will typically also be the lowest point in the HTF loop plumbing. This allows complete draining; otherwise, the lowest drain could be on the pump station, potentially 4 to 6 feet above the low point, which will add to the mess when the tank needs replacing.

Many installers prefer to locate the HTF pressure relief valve outside, at the collector(s). Pump stations are only suitable for installation inside, so the integrated pressure

Web Extra

For the ins and outs of solar hot water system heat exchangers, visit www.homepower.com/webextras

relief valve may require an additional drain line. This drain may be able to be run in the same line as the drain for the temperature and pressure-relief valve on the storage tank, but in many locales it requires its own piping.

The Word on the Street

Installers agree that building a pump stack from individual components can be time-consuming—three to four hours (or more) is typical for plumbing the copper and brass fittings, gauges, valves, and pump, and installing a controller. Often this can be done ahead of time, though space and time constraints may require that it be done at the installation site. Furthermore, the tank may be more difficult to transport with the plumbing components attached. Either way, a bunch of fittings, valves, gauges, and components are required, as well as the means to pressure-test the final product.

Because there are fewer connections required and a pump station can quickly be installed on the tank or wall, it is often easiest to perform all the work on-site. But first be sure to verify that all of the required adapters and components are included and, as with all systems, perform a pressure-check before charging it.

Casey McDonald, an installer for Solar Technologies in Santa Cruz, California, has installed many SHW pump stations. "Pumping stations both make the system look more professional and simplify installation, and the fittings are more durable than standard hardware-store quality."

According to McDonald, servicing pump stations is easier, too. "On custom, built-on-site systems, a lot of time is spent on trying to figure out the layout of the plumbing." He says that pump stations cost more than build-up systems, and proprietary parts, such as metric-to-NPT adapters, can be difficult to find if one is missing or damaged. "Definitely don't assume that all the pump station fittings are tight right out of the box," McDonald says. "Pipe dope and pipe-thread tape first can avoid chasing leaks later."

Justin Trievel has been installing solar hot water systems for EV Solar Products, Inc. in Chino Valley, Arizona, for several years, using pump stations and building pump "stacks." He agrees that while pump stations are more expensive than individual components, they do save a good amount of time.

However, Trievel says that there are more limitations for nonstandard installations. He usually uses unmatched brands of pump stations and tanks, prefers to hang the pump station on the tank when possible, and says he has had only a few issues with the individual components in the pump stations. He is trying different brands and models of pump stations, as well as fully integrated systems, with all of the components pre-mounted on or in a tank.

Access

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Connecting Inverters to the Grid

Part 1: Load-Side Connections

by John Wiles

Properly connecting a grid-tied inverter to the utility grid is critical to the safe, long-term, reliable operation of the entire system. The AC output circuit requirements and the circuits that carry the inverter current in the premise's wiring are somewhat complex, but meeting *National Electrical Code* requirements is a must to ensure a safe and durable system.

Even though energy flows from the inverter to the utility, it's at the utility end of this circuit where the currents originate that can harm the conductors when faults occur. Any overcurrent protection should be located at the *utility* end of the inverter AC output circuit—not at the inverter end.

Although the inverter may require an external disconnect, if that disconnect function is by a circuit breaker, then the conductor ampacity calculations may be more complicated (see below). It is good practice to install the inverter near the back-fed load center so that the back-fed breaker commonly used to interconnect the inverter with the utility can also be used as the AC inverter disconnect required by *NEC* Section 690.15. This places the overcurrent device at the utility-supply end of the circuit and groups the AC disconnect for the inverter near the DC disconnect. Note that the local utility may also require a separate visible-blade, lockable disconnect.

Load-Side Connection

There are two types of connections allowed by the *Code* for interfacing any utility-interactive inverter's output to the utility power. These connections are made on either the supply side or the load side of the main service disconnect of a building or structure (690.64). The load side of the main service disconnect is the most common connection used for PV systems smaller than 10 kW. Section 690.64(B)—moving to 705.12(D) in the 2008 and 2011 editions—covers the requirements and it is heavy reading at best. (Note that changes exist in Section 690.64 between the *2005 NEC* and the *2008 NEC*. For more information, see *Code Corner* in *HP126*.)

Since the 1980s, code-making experts have maintained that 690.64(B)(2) should be rigorously applied to any circuits (panel-board bus bars or circuit conductors) supplied from multiple sources where protected by overcurrent protective devices (OCPDs) from each source. Such sources would include the output of PV inverter(s) and the utility supply.

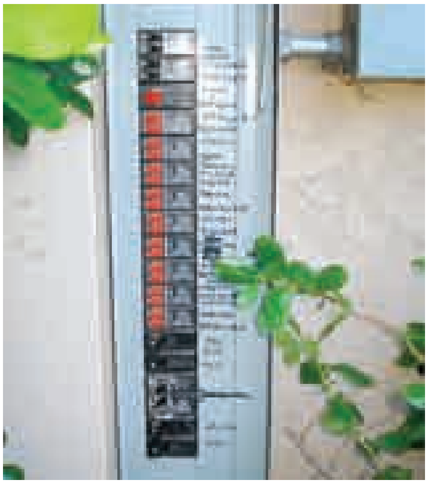
This *NEC* section requires that the ratings of all OCPDs *supplying* power to a conductor or bus bar be added together for the necessary calculations. The sum of the ratings of those breakers may not exceed 120% of the rating of the bus bar or the ampacity of the conductor:

PV OCPD + Main OCPD ≤ 1.2 R, where R is the ampacity of the conductor or the bus bar rating.

120% Factor & Breaker Location

The demand factors on residential and small commercial systems are such that it is unlikely that the conductor or panel would ever be loaded to 100% of rating. Even if the sources could supply 120% of the rating of the bus bar or conductor, loads connected to that same bus bar or conductor—so long as they don't exceed the bus bar rating—would not pose an overload problem. As long as the actual load currents (limited by the ratings on the load breakers) do not exceed the bus bar rating, the currents through the bus bar to these loads cannot exceed its rating—even if greater supply currents were available (from either the utility through the main breaker or from the PV system through the back-fed PV breaker). The PV array will push power onto the bus bars, and the utility will simply supplement the additional power required by the loads. That is, the grid doesn't try to push extra power onto the bus bars simply because it has more headroom left on the circuit breaker.

To use this 120% factor, any back-fed breaker carrying PV current must be located at the opposite end of the bus bar from the main breaker or main lugs supplying current from the utility. This requirement keeps the supply currents distributed across the bus bar, rather than concentrated on one part of the bus bar. The same location requirement applies to the supply overcurrent devices on any conductor. If the PV inverter OCPD cannot be located as required, then the 120% in the above requirement drops to 100% and an installation using the load-side connection becomes more difficult.



The most rudimentary requirement is making sure there's an open space for the inverter breaker(s) on the opposite end of the bus bar from the main circuit breaker.

Courtesy John Wiles (2)

The Article 240 tap rules do not apply to these inverter connections since they were developed only for circuits with one source. The OCPD for the inverter output circuit should be located, as mentioned above, at the point nearest where the utility currents could feed the circuit in the event of a fault (i.e., in the main service panel or inverter AC combining panel, rather than at the inverter). It is a common mistake to apply the Article 240 tap rules incorrectly and locate the OCPD at some point away from the tap point. This may create conductor protection issues when multiple sources are involved.

Example Calculations

1. A dwelling has a 125-amp service panel (bus bar rating) with a 100 A main breaker at the top. How large can the back-fed PV breaker be that must be located at the bottom of the panel?

PV OCPD + Main OCPD ≤ 120% of service-panel rating
120% of panel rating = 1.2 x 125 A = 150 A
PV OCPD + 100 A ≤ 150 A
PV OCPD ≤ 150 A – 100 A or 50 A

The PV OCPD can be up to 50 A.

2. Suppose it was a 100 A service panel with a 100 A main breaker. What PV breaker could be added?

PV OCPD + 100 A ≤ 1.2 x 100 A
PV OCPD + 100 A ≤ 120 A
PV OCPD ≤ 120 A – 100 A or 20 A

The maximum PV back-fed circuit breaker would be rated at 20 A.

3. A 200 A main panel with a 200 A main breaker:

PV + 200 A ≤ 1.2 x 200
PV ≤ 240 A – 200 A or 40 A

Up to 40 A of PV breaker is allowed—in this case, it could be any combination of breakers that add up to 40 A on either line 1 or line 2 of the 120/240 V service panel (i.e., each bus bar can accommodate 40 A of back-fed circuit breakers).

4. Working the problem from the inverter end, we start with the continuous rated inverter output current. This is usually the rated power divided by the nominal line voltage, unless the inverter specifications list a higher continuous output current (sometimes given at a low line voltage).

A 3,500 W, 240 V inverter has a rated AC output current of 14.6 A (3,500 W ÷ 240 V). According to Section 690.8, the output circuit must be sized at 125% of the rated output, or 18.3 A (1.25 x 14.6 A).

The next larger overcurrent device would be a 20 A OCPD; consistent with the use of 12 AWG conductors if there were not any significant deratings applied for conditions of use. This system could be connected to a 100 or 200 A panel (where the main breaker in each panel has the same rating as the panel), provided that the back-fed 20 A breaker could be located at the bottom of the panel.

The equations would have to be revisited if the PV breaker could not be located at the opposite end of the panel from the main breaker (or utility input on a main lug panel). At this point, the 120% allowance drops to 100%. Normally, reducing the size of the main breaker would require a full *NEC* Chapter 2 load analysis on the building—and that analysis will frequently show that the breaker cannot be reduced.

There is sometimes a tendency to use whatever breaker and wire gauge that is easily at hand: 30 A breakers and 10 AWG conductors are common. While this would pose no problems for conductor ampacity or protection, bus bar calculations would need to be performed as shown above. Additionally, the inverter specifications may limit the maximum size of the output OCPD. If so, higher-rated breakers may not be used, according to Section 110.3(B).

No Bottom Breaker Position?

If the back-fed PV OCPD cannot be located at the bottom of the panel (assuming a main breaker at the top or main lugs at the top) or at the opposite end of the circuit conductor from the supply, it is not possible to install the back-fed breaker without changing something, and that 120% allowance drops to only 100%. In the above equations, no PV back-fed OCPD could be added to any service panel that has the same rating as the main breaker rating. The 100%-of-the-panel-rating factor (instead of 120%) would equal the rating of the main breaker and the equation would force the PV breaker rating to be zero.

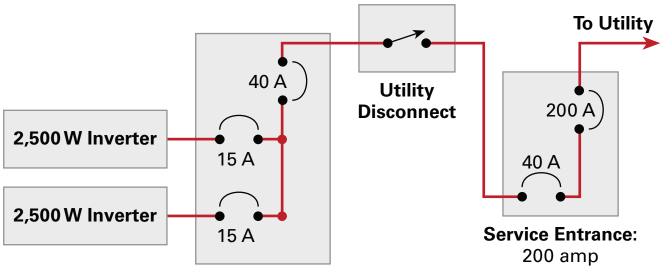
In a few cases, conducting an *NEC* Chapter 2 load analysis might reveal that the service panel was oversized. For example, if a 200 A panel was installed with a 200 A main breaker to provide extra circuit positions, when a 150 A panel would have met the house's loads. In this case, it might be possible to substitute a 150 A main breaker for the 200 A breaker. Even without the bottom position being open, 50 A of PV breaker could be installed.

Systems with Multiple Inverters

Some systems use more than one inverter. If the local utility requires an accessible, visible-blade, lockable disconnect on

A multiple-inverter installation. Note DC and AC disconnects for each inverter, a PV subpanel combiner, and a whole-system AC disconnect.

One-Line Diagram of Two Inverters & an AC Combining Panel



the output of the PV inverters, then more than one inverter could not be connected directly to the main panel. The two or more inverters would have to have their outputs combined in a PV AC subpanel before being routed through the utility disconnect and then to the main panel. The disconnect is not normally fused, but some are, depending on the system configuration. The PV AC subpanel rating, the rating of the disconnect, and the ampacity of the conductor to the main panel are also dictated by 690.64(B) requirements.

Here is another example: The dwelling has a 200 A main service panel with a 200 A main breaker. There is an empty breaker position at the bottom of the panel. The utility requires an external disconnect switch. The goal is to accommodate a PV system that has one 3,500 W and one 4,500 W inverter. A PV AC panel will be used to combine the outputs of the two inverters. The output of the PV AC panel will be routed through the utility disconnect and then to a single back-fed breaker in the main service panel.

The ratings of the output circuits of each inverter are:

Inverter 1:

3,500 W ÷ 240 V = 14.6 A
1.25 x 14.6 A = 18.3 A

Use a 20 A breaker and 12 AWG conductors.

Inverter 2:

4,500 W ÷ 240 V = 18.8 A
1.25 x 18.8 A = 23.5 A

Use a 25-amp breaker and 10 AWG conductors.

The 20 and 25 A breakers are mounted at the bottom of a PV AC panel and a main-lug-only panel will be installed. Normally, no loads will be connected to this subpanel. It will be dedicated to the PV system. Note that 690.64(B)(2) states, "In systems' panelboards connected in series, the rating of the first overcurrent device directly connected to the output of a utility-interactive inverter(s) shall be used in the calculations for all bus bars and conductors." Although this scenario would seem to be non-*NEC* compliant, since 20 A + 25 A = 45 A, which would be greater than the 40 A allowed to back-feed the main 200 A service panel with 200 A main breaker, this section of the *NEC* should have been a permissive requirement—rather than

Two inverters and their AC combiner, with breakers.

mandatory—and only applied where beneficial to the overall design. There is currently an effort to fix this for the 2011 *NEC*.

The next step is to calculate the back-fed breaker that must be placed in the main service panel to handle the combined output of both inverters from the PV AC subpanel and to protect the conductor carrying those combined outputs under fault conditions from high utility currents.

The combined currents from both inverters are:

14.6 A + 18.8 A = 33.4 A

The overcurrent device should be 35 A.

The ratings of OCPDs supplying the conductor from the PV AC subpanel to the 35 A breaker, the utility disconnect switch, and supplying that PV AC subpanel are now defined as 35, 20, and 25 A.

The subpanel rating and the ampacity of the conductor are determined by 690.64(B)(2). It would be incorrect to guess that the answer might be 35 A as it would be in a normal load subpanel.

35 A + 20 A + 25 A ≤ 120% R, where R is the panel rating or the ampacity of the conductors

80 A ≤ 1.2 R
80 A ÷ 1.2 = 66.7 A

The subpanel size would be rounded up to a 100 A (because there are very few 70 A or 75 A panels with multiple breaker positions), and a main-lug-only panel would be used. The conductor size for this ampacity would be 4 AWG since the breakers would typically have 75°C terminal temperature limits and a 6 AWG conductor operating over 65 A would get warmer than 75°C.

The load-side connection for the utility-interactive PV inverter is not the easiest subject to understand, but the correct application of these requirements will yield a safer, more durable system. When the requirements of load-side connections become complex and expensive, a supply-side connection is used, and we will examine those requirements in Part 2 in the next issue.

Access

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Southwest Technology Development Institute • www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/Codes-Stds.html • "Perspectives on PV" and *Code Corner* articles, and *Photovoltaic Power Systems & the 2005 National Electrical Code: Suggested Practices* by John Wiles


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The French Nuclear Myth

by Michael Welch

Nearly every time I write about the impracticality of nuclear energy being a realistic solution to our energy problems and to human-caused climate change, I receive responses from readers saying that nuclear energy works well for other countries, most notably France.

The French nuclear program is often touted as a shining example of how well nuclear energy can be done—but in reality, the program is not all that it's cracked up to be. Even if it were, nukes are problematic, no matter which country they are in. The mere fact that nuclear radiation is unhealthy is often enough for any detractor to make a strong case. After all, containing the dangerous and deadly radiation during power plant operation relies entirely on the human element—all the way from humans designing the systems to having humans operate those systems properly. It is a given that humans are fallible, and mistakes or lapses happen. When it comes to nuclear energy, a small mistake can quickly grow into a deadly, widespread catastrophe.

Among the several holy grails of the nuke industry is to design a fail-safe reactor system that will make sure radiation is not released. Here in the United States, that quest has been fueled by billions of tax dollars and more than half a century spent on research and failed efforts. In France, a similar but expanded effort is in place—this lack of success is the reality of the nuclear situation, and only far-fetched speculation could claim that the goal will ever be reached.

Another holy grail is to find a satisfactory means of dealing with highly poisonous and long-lasting nuclear waste, which is a by-product of both nuclear energy and nuclear weapons materials-making. Again, both countries have equally failed efforts, but with different methodology and results.

French Energy

In the middle of the twentieth century, France began to adopt a mind-set that was becoming common around the world: Nuclear power would be "too cheap to meter" and be able to meet all electricity needs in the developed world, even into the unforeseeable future. In 1945, France established the Commissariat à l'Energie Atomique (Commission for Atomic Energy, or CEA) to oversee all research and development of both nuclear military weapons and the nuclear generation of electricity.

Construction of the first energy reactor site began in 1952, with commercial production getting underway in 1956—about the same time that U.S. reactors came online. But France's bigger move toward nuclear energy occurred in the 1970s, when the Arab oil embargo started a worldwide push for alternatives to oil. French officials took advantage of the situation by greatly overestimating growth in electrical usage, eventually saddling the small country with 59 nuclear reactors, which now provide approximately 80% of the country's electrical energy.

Taxpayer money flowed freely into the coffers of nuclear R&D, reactor design, and construction, subsidizing the industry to make France's electricity rates far lower than the cost of producing the energy. Today, France is the world's largest net exporter of electricity, due to its very low (subsidized) cost of generation.

But the agencies involved were only partly interested in building plants for France. The plan was, and still is, for France to be far ahead of other countries not only in nuclear usage, but also in the export of reactors to other regions of the world. France hoped to export one reactor for every one built in France—but those sales expectations never materialized. Only nine reactors have been exported and finished to date.

Like any organization involved in such a massive plan, the French agencies were shrouded in secrecy, releasing little information to the rest of the world. The government owns a controlling interest in the agencies and organizations that operate France's nuclear business, and the nuclear industry has morphed into a quasi-governmental/industrial monolith called Areva.

French Disconnect

Huge subsidies laid the groundwork for the U.S. nuclear industry, with a public relations machine that continues to tout France as a prime example of a successful nuclear power program. But without a watchdog agency, like the marginally effective Nuclear Regulatory Agency here in the United States, problems with nuclear energy generation in France aren't readily publicized.

The French push for electricity "too cheap to meter" resulted in the French myth of energy autonomy. According to an article in *The Bulletin of Atomic Scientists*, fossil fuel provides more than 70% of France's final energy (which includes more than just electricity), all of which is imported from outside the French borders.

Another mythically successful part of the French nuke industry is how they deal with nuclear waste, which is really

irradiated fuel. France "reprocesses" the waste into more usable fuel and isotopes that can be made into bombs. The United States used to reprocess fuel, but it is a very dirty process that is difficult to contain. And some by-products from processing the irradiated fuel are exactly what some developing countries would love to have to make nuclear weapons.

The U.S. government has a strong policy of discouraging bomb-making materials, and has long intended to be an example for the world in that regard. So while France reprocesses irradiated fuel, the United States has chosen to store its nuclear waste. Across our nation, at all nuclear power plants and at some interim storage sites, sit tons of irradiated fuel waiting for a national repository. Our repository was planned for Yucca Mountain in Nevada, but state opposition there has been effective and the facility will likely never open.

The U.S. nuke plant owners would love nothing more than to pass the waste on to the government so they do not have to deal with it. In their corporate, bottom-line minds, any method of removal is better than local storage. So once again, they are promoting the use of reprocessing, and guess who they hold up as another shining example of what can be done in that field? Correct: the mythical France.

But reprocessing is fraught with problems, and French have their share. By the end of 2004, nearly 900,000 cubic meters of nuclear waste had been made in France. Of this amount, 40% has been through reprocessing. According to Greenpeace, an organization that keeps a close eye on what is being dumped into the seas, about 12,000 cubic meters of radioactive processing by-products were dumped into the English Channel by the nuclear reprocessing plant on the coast at Marcoule in the late 1960s.

If fuel is not reprocessed, there is basically only one waste stream to deal with—the irradiated pellets. Reprocessing is the separation of those pellets into more usable fuel, isotopes that can be used in bombs, and other radioactive waste streams. While reprocessing decreases the end-volume of the nuclear waste (by 1% or so), it requires extra handling of the irradiated fuel, handling multiple waste streams at multiple facilities, and the extra transportation that comes with it.

France uses acid to extract plutonium and enriched uranium. The process releases massive amounts of radioactive gases and liquids that should be contained but often are not—releasing thousands of times more amounts into the environment than the everyday operation of nuclear reactors. Even after reprocessing, large amounts of different radioactive wastes remain. According to Beyond Nuclear, an advocacy group promoting alternatives to nuclear power, the "low-level" radioactive waste from the reprocessing facility at LaHague is disposed of in the English Channel—a legal quirk, since putting it in barrels and dumping at sea would violate the 1970 London Dumping Convention. LaHague reprocessing also releases radioactive gases, including krypton-85, and now local environmental contamination is 90,000 times higher than what is found in nature. The site also discharges carbon-14, considered to be one of the most damaging radioactive isotopes to human health, as well as radioactive carbon dioxide. The list of reprocessing problems goes on and on…

Local & Export Problems

Radioactive accidents and releases are not limited to the reprocessing facilities. The mythically safe French reactors have been the site of many nuclear "incidents," such as the 2008 release of liquids containing uranium at the Tricastin Nuclear Power Center, which contaminated the Gaffière and Lauzon rivers. French officials banned the use of this water for drinking and watering crops, as well as swimming and water sports in the rivers.

Areva's reactor export program is also having serious problems. They currently have two reactor export projects in development. A French reactor type called the European pressurized reactor (EPR) is under construction in Finland. As of July 2009, the reactor is at least three years behind schedule and 60% over budget, due to technical flaws, including substandard parts.

Two EPRs for China are also on hold, though the reasons and potential outcome is not being publicized. China negotiated a $12 billion deal with Areva to build two reactors, but the planned August groundbreaking ceremony was not held, and construction was not approved by China—Areva

is claiming the delay is due to Chinese officials being too busy with weather problems. But French activists with Sortir du Nucléaire are speculating that the project may never go forward, claiming that contrary to French official statements, the Chinese had informed Areva in June that the ceremony would not be held on the August date.

Speculative, yes, but after failing for decades to come up with an exportable technology, France has put all of its export eggs in the EPR. At this point, and with the Finnish reactor's problems, the only country to ever get an EPR is France.

Too Hot

According to French environmentalists, the country's rabid promotion of electricity usage (to help use up the oversupply from too many nuke plants) has made super-consumers of the French public. There is little movement toward conservation and efficiency so far, although new proposals for green businesses, including efficiency and renewables, are working their way through government. Sure, they have lots of electricity to use, but cutting back in France would allow other countries to buy the excess energy, which would reduce the demand for greenhouse gas-producing fossil fueled electricity in the other nations, and mean fewer new power plants. With France being such an avid promoter of expensive nuclear technologies, little funding or other impetus for renewable energy is left. France is surrounded by nations that have long opted for RE, but the country has been living in the energy Dark Ages.

Another fact surrounding climate change is that river temperatures are rising, and water is crucial to cooling nuclear reactors. During the 2003 heat wave, 17 French reactors were forced to shut down or decrease power because of too-high water temperatures. France allowed the discharge of hotter water during the 2006 heat wave, but high-temperature discharges are damaging to a river ecosystem, and can kill aquatic life or force river dwellers away from their habitat.

The final myth to be addressed is that the French people love and want nuclear energy. This has been true to a degree—it is to be expected from a populace that has built up such pride in their nation and government since World War II. They want to believe in their government and have been sold a bill of goods by regulators that are entrenched in the idea of nuclear energy.

But that is changing, as the citizenry has been discovering the mythology of French nuclear power. According to a recent poll, about 60% favor a phaseout of nuclear energy. In April 2006, more than 25,000 people demonstrated against new nuke plants in Cherbourg. In 2007, another 60,000 rallied against nuclear power in five cities. More than 50,000 signed a petition asking for a referendum on a nuke dump in northeastern France, which was ignored by French politicians. Today, the activist group Sortir du Nucléaire includes 820 non-governmental organizations.

According to a March 2009 *Wall Street Journal* article which reported on a survey from the consulting firm Accenture. "hardcore French support for nuclear power stands at just 20%, similar to levels in anti-nuclear Germany. Over the past three years, opposition to nuclear power has grown in France more than in any of the other countries in the survey."

Fewer and fewer French are in support of their failing nuclear experiment, and in spite of Areva's and the U.S. nuclear industry's promotion of the French nuclear myth, the emperor's clothes are decaying and falling off. It is only a matter of time before the world recognizes the French fable, which will lead to a worldwide decline in the use of nuclear energy, freeing up resources to allow the RE future we all need and deserve.

Access

Michael Welch (michael.welch@homepower.com) is fighting dirty energy and promoting a clean energy future along with the Redwood Alliance in Arcata, California.


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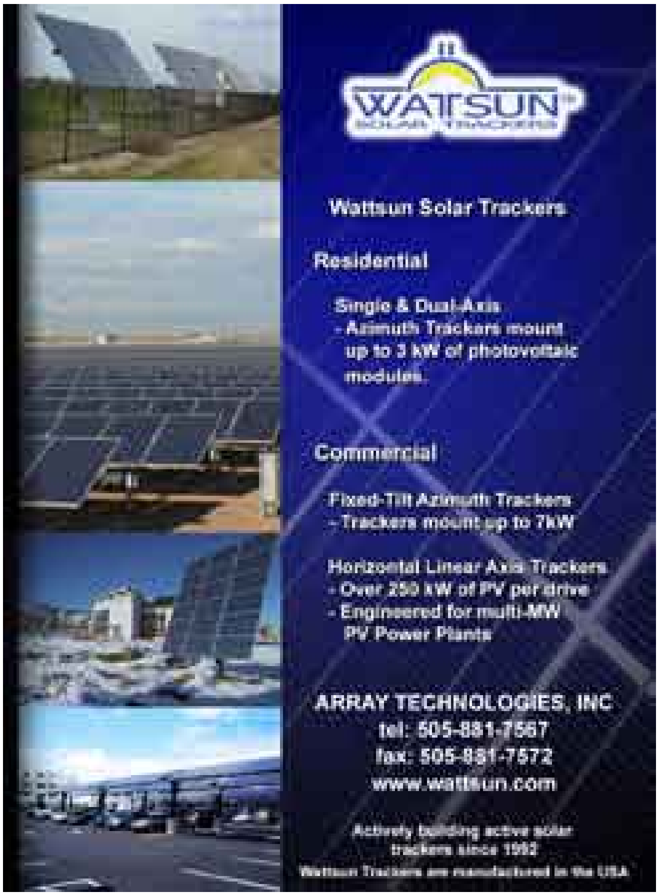
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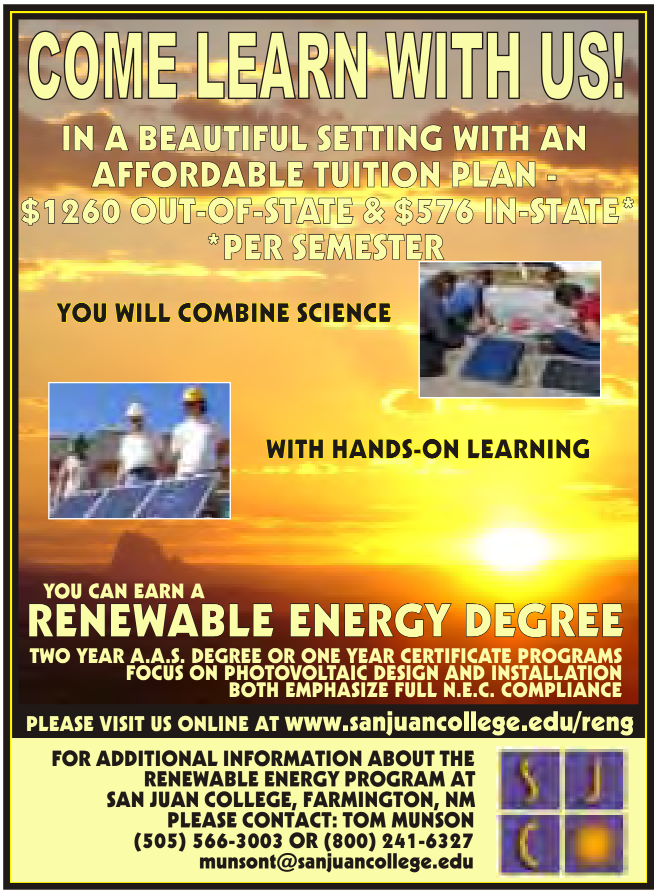
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Watt Wisdom

by Kathleen Jarschke-Schultze

Although I am far from a tech expert, the last 23 years of living off-grid have taught me a thing or two. When I consider buying anything electrical, I check its power demands, either by checking the ratings on the nameplate or by looking up the specs online. This has become second nature, and I do not give the process itself much thought.

But I am reminded now and again that being aware of one's electrical usage is not on the minds of most people. I suppose they consider it when they get their electric bill, but not when they turn on the toaster or microwave. To a vast majority, electricity is magic: See, on the wall, there is an outlet—electricity comes out of there. All you have to do is plug something in, and it will run.

Fair Knowledge

Every year, my husband Bob-O and I assemble a crew of 10 and spend a week at the Oregon Country Fair in Veneta. The Fair is open to the public for only three days, but we go early to set up five battery-based PV systems to power entertainment stages and so food booths can have light at night.

Our home base is Energy Park, where booths provide the paying public with information on a variety of green and renewable options. Unlike the rest of the fair, nothing is sold in Energy Park—it is all about education. There are solar showers available and a 600-watt, battery-based PV system at the information booth. This system also runs the Kesey Stage in Energy Park and night lighting for the info booth, along with some battery charging.

Several years ago, we began using some of the PV-generated electricity to run an ingenious cell-phone charging station. Ian Whitelaw, the designer, used all recycled parts to build the phone cubbies. We were able to charge 40 cell phones simultaneously from the PV system. We laid ground rules for this free service and made signs accordingly: You must

provide the charger. Label your phone and charger with your name, booth number (or home phone if you are not in the Fair Family), and the time you started charging. Do not leave your phone for longer than two hours. Leave your phone at your own risk—we do not monitor the charging station.

Phone Phairy

Oh yes, we figured we could trust people to follow directions. Most people followed the directions and were happy to be able to charge their phones at the Fair. But the people who didn't follow directions are the ones who stand out in my memory.

It quickly became apparent that someone would have to monitor the charging station. I volunteered to be the Phone Phairy for awhile. I stopped people from using other people's charge cords. I insisted that they label their phones. I didn't let anyone charge cameras, electronic games, or MP3 players—the service was for communication devices only. No, I wouldn't let you paw through all the phones to see if your friend's phone was there. I removed phones left longer than two hours from the charger and put them in a box to the side of the charging station. I lost my sense of humor. Silly me, I expected people to act like responsible adults.

I kept my post for six hours, then abandoned it for the evening when the magic wore too thin. I began to wish I had a big Phairy wand and a couple of good obedience spells to use. After the Fair closes to the public, there are still thousands of people camping on the grounds, and the charging station continued to be full of phones through the night. One woman left her phone in the charging station at 5 p.m. and came back for it at 6 p.m. the next day, only to discover it was gone. She had not labeled it (nor followed the two-hour charging rule). And we had no way of knowing who took the phone.

The next day I worked a two-hour stint and was relieved by an Energy Park friend. Throughout the day, we would occasionally check on the charging station. We were doing a bang-up business. The cubbyholes were always full of charging phones. We received a lot of dollar donations, which went into a fund for Energy Park projects.

The Stuff of Legend

We set up the charging station again at last summer's Fair. The cubbies were full almost immediately. Sometimes there was a Phone Phairy monitoring the situation, sometimes not. It was still not an "official" position, but we tried to have someone there most of the time to keep the possibility for cell-phone confusion at a minimum.

In its strategic location behind the Information Booth, the charging station operated without incident for several hours, until a 20-something woman, hefting a big basket, strolled into Energy Park and disappeared around the back of the booth. Sitting at the Information Booth, we did not think anything of it—people were always bringing stuff to their campsites or taking it out. We didn't even pause our conversation.

However, a minute later, a shout of "No, stop! Unplug that right now!" got our attention. The mystery basket had been filled with wrinkled clothes, and the prospect of unwrinkling them—by plugging her iron into an empty outlet at the charging station—was just the opportunity she was looking for. Smoothing a towel on the ground, she had plugged her iron into the charging station and was about to turn it on and iron all her laundry. Fortunately, Bob-O happened to be nearby, talking to a booth person, and saw her in time.

The phone charging station—no big loads allowed.

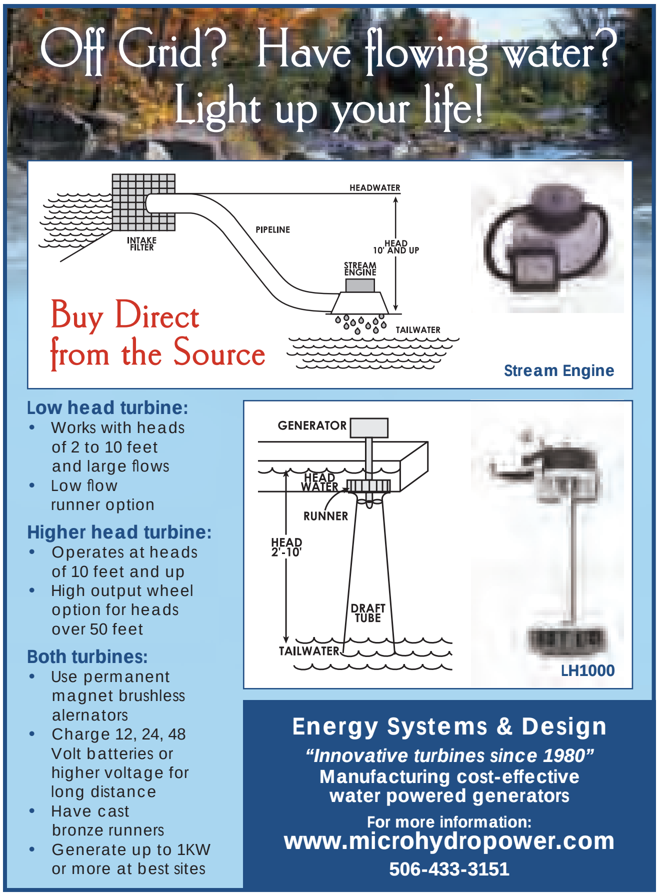
An iron?! Alarms bells would have gone off in my head, but all she saw was an electrical outlet. The fact that it was solar-powered and that an iron would suck so much juice from our batteries that we couldn't run the stage, let alone charge any phones, simply did not occur to her. The sign, "Cell phones only!" obviously did not apply to her.

While we'd escaped one electrical catastrophe, the next day was cloudy and raining. We covered the charging station with a cloth and spent a good part of the day explaining to eager cell-phone chargees that the solar-powered charging station would not be available until there was sunlight to recharge the battery bank. A few hopefuls snuck in their phones under the cloth, hoping for some good old electrical magic. To no avail, I might add. It was, however, an opportunity to do a little one-on-one teaching about solar power and energy consumption.

We had unleashed solar power to the public—and now we had to teach them how to use it. Or, as it seems to me now, how not to abuse it. Remind me, was it fire or electricity that was Prometheus's gift? Electricity powers a greater portion of our lives and livelihoods. We need to have a healthy respect for it—and use it wisely.

Access

Kathleen Jarschke-Schultze (kathleen.jarschke-schultze@homepower.com) is yodeling with joy over her new Jøtul wood heater at her off-grid home in northernmost California.



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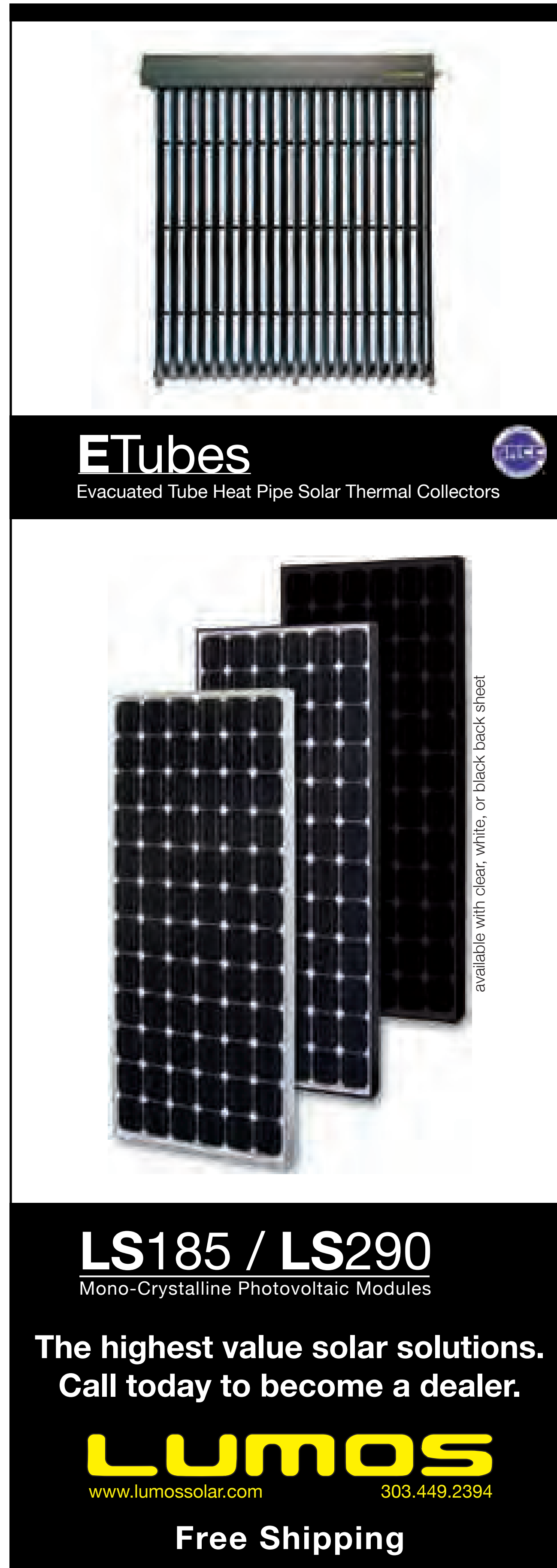
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4) Paid Distribution by Other Classes of Mail Through the USPS	30	29
c. Total Paid Distribution	48,128	46,673
d. Free or Nominal Rate Distribution		
1) Outside-County	2,591	2,408
2) In-County	0	0
3) Other Classes Mailed Through the USPS	0	0
4) Distribution Outside the Mail	4,377	3,131
e. Total Free or Nominal Rate Distribution	6,968	5,539
f. Total Distribution	55,096	52,212
g. Copies Not Distributed	12,862	11,388
h. Total	67,958	63,600
i. Percent Paid	87.4%	89.4%

16. This statement of ownership will be printed in the December/January 2010 issue of this publication.
17. I certify that the statements made by me above are true and complete. Scott M. Russell, Operations Director, 9/22/09.

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Wind Turbine Transmission Wire Sizing

Current in wire produces heat, so correctly sizing wires is important—both for safety and energy efficiency. If the wire is too thin for the rate of charge flow (known as "current"), the temperature rise will degrade the insulation, increasing the risk of fire. If the wire run is too long for the size of the wire, the heating will waste too much energy.

Current

With small wind-electric systems, the nominal DC current is equal to the turbine's rated power divided by the system voltage. But wind turbines sometimes exceed their rated power, so check with the turbine supplier for maximum current ratings. Electrical codes also require additional safety margins for wiring. Keep in mind that 12 V systems will have four times the charge flow as 48 V systems to deliver the same amount of power.

Most small wind turbines produce wild three-phase AC. Three wires carry this to the rectifier, where it is converted to DC. At any given moment, only two of these wires really conduct current. Sizing for safety, you can assume that the AC RMS current in each wire is 82% of the DC. The energy loss in the three wires will be similar to the loss in two wires of the same size carrying the full DC current.

Ampacity for Safety

Wires have a maximum safe current—known as ampacity—that is determined by the wire size, the temperature rating of the insulation, and other installation factors (see table). Choose an ampacity column in the table that relates to the wire's temperature rating. So long as the ampacity of the wire is higher than the maximum possible current, the circuit will be safe.

Voltage Drop

The wind turbine has to produce extra voltage to push charge through the wires to the load. A good way to look at a circuit's energy efficiency is to calculate this voltage loss in the wires as a percentage of the system voltage. If a 48 V circuit drops 2 V, then the wind turbine would need to produce 50 V, and the energy lost in the wires would be 2 ÷ 50, or 4% of the total. Here is a formula for the loss in a given situation:

Percentage loss = (100 x ft. of one-way wire run x amps) ÷ (ft. per ohm x system voltage)

The table shows feet of wire run *one way* for 1 ohm of resistance, based on 100°F temperatures.

photo courtesy www.brooksSolar.com

The wire run from a good wind site to the point of use can be quite a distance.

Wire Sizing Table

Wire Size (AWG)	Ampacity at 167°F (A)	Ampacity at 194°F (A)	Ft. Per Ohm (One-Way Run)
8	50	55	709
6	65	75	1,127
4	85	95	1,793
3	100	110	2,261
2	115	130	2,851
1	130	150	3,595

Sample Calculation

Say you have a 1.2 kW, 24 V turbine. Rated current is 50 ADC (1,200 ÷ 24), but various safety factors suggest a maximum of 75 A. AC current would be 62 A (75 x 0.82), and a minimum safe wire size would be #6 AWG.

Now suppose the one-way wire run is 200 feet.

Percentage loss = (100 x 200 ft. x 50 A) ÷ (1,127 ft. per ohm x 24 V) = 37%

This is a worst-case situation. Most of the time, the turbine will generate less current, perhaps 10 to 15 A, and operate at a 7 to 11% voltage drop. But a thicker cable will most likely still be justified if you weigh the costs versus the benefits. Be sure to always check the turbine manual for recommendations.

—Hugh Piggott

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